FINAL REPORT
BASELINE METEOROLOGY AND AIR QUALITY IN THE FOLSOM DISTRICT

PART 2 - CHAPTER 4
DISPERSION METEOROLOGY

Submitted to:

Bureau of Land Management
Sacramento, California

Prepared by:

W. P. Lynott
B. Garelick
D. Rykaczewski
H. Frentz
D. Cover

October 2, 1979

SCIENCE APPLICATIONS, INC.
ENVIRONMENTAL SCIENCE AND TECHNOLOGY

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4. DISPERSION METEOROLOGY

4.1 INTRODUCTION

An understanding of the dispersion potential of a region is essential in determining the impact of both existing and proposed sources of ground level and elevated emissions of pollutants. Areas that are plagued with poor dispersion conditions for extended periods of time are apt to suffer stringent limitations on land use and industrial development. Under such poor dispersion conditions, seemingly insignificant sources of pollution can result in excessive concentrations over large areas. As discussed in Seciton 6, The Clean Air Act Amendments of 1977 impose strict regulatory requirements on new sources of air pollution in areas with high ambient pollutant concentrations.

The dispersion potential within the Folsom District has been developed through the maximum utilization of available data. The following sections describe the dispersion meteorology of the Folsom District in terms of the following analyses:

- Data Sources
- Prevailing Winds
- Atmospheric Stability
- Mixing Heights and Inversions
- Typical and Worst-Case Conditions
- Air Basins
- Fire Weather
- General Dispersion Modeling

Surface data suitable for use in the analysis of the Folsom District dispersion meteorology are derived primarily from the National Weather Service (NWS) first-order meteorological stations. The availability of mixing height, inversion and winds aloft data is limited to those stations that take routine measurements of upper air winds and temperatures. Oakland is the only NWS station of this type in the District. However, upper air winds and temperature data are also available at other sites as part of a program being conducted by the California Air Resources Board (CARB). Additional data from lower-order NWS or other governmental and special interest stations have been reviewed and included where they provide additional significant information regarding the characterization of the dispersion meteorology of the Folsom District.

Section 4.2 provides a review of the general principles of dispersion meteorology. Sources of data which have been used to describe the dispersion potential of the Folsom District are discussed in Section 4.3. The discussion then turns to a review of specific dispersion parameters including prevailing winds, atmospheric stability, mixing heights, and inversions in Sections 4.4 through 4.6, respectively. More detailed analyses are then provided, including a review of typical and worst-case conditions

for a variety of potential sources in Section 4.7. The air basin analysis approach to dispersion meteorology is outlined in Section 4.8. Section 4.9 provides a discussion of the impact of dispersion meteorology on burn conditions while section 4.10 describes concepts of air quality modeling including suggestions as to the manner in which the data presented in this document should be interfaced with appropriate models. Finally, Section 4.11 provides a review of sources of assistance to BLM personnel encountering problems in dispersion meteorology while Section 4.12 provides a glossary of terms.

4.2 PRINCIPLES OF DISPERSION METEOROLOGY

Dispersion meteorology provides an evaluation of the capability of the atmosphere to disperse airborne effluents in a given geographical region. That capability depends largely on the critical meteorological parameters wind speed and direction, atmospheric stability and mixing height. The topography of the region also plays an important role.

The air pollution cycle can be considered to consist of three phases: the release of air pollutants at the source, the transport and diffusion in the atmosphere, and the reception of air pollutants in reduced concentrations by humans, plants, animals, or inanimate objects. The major influence of meteorology occurs during the diffusion and transport phase. The motions of the atmoshphere which may be highly variable in four dimensions, are responsible for the transport and diffusion of air pollutants.

Although the distribution of a cloud of pollutant material with time will depend on the summation of all motions of all sizes and periods acting upon the cloud, it is convenient to first consider some mean atmospheric motions over periods on the order of an hour.

The following sections discuss (1) the principles of turbulence and diffusion, (2) the key dispersion parameters, (3) the role of topography in diffusion and (4) atmospheric chemistry. Modeling is discussed in detail in Section 4.9 while instrumentation is reviewed in Section 7.

4.2.1 Principles of Turbulence and Diffusion

When a small concentrated puff of gaseous pollutant is released into the atmosphere, it tends to expand in size due to the dynamic action of the atmosphere. In so doing, the concentration of the gaseous pollutant is decreased because the same amount of pollutant is now contained within a larger volume. This natural process of high concentrations spreading out to lower concentrations is the process of diffusion.

Atmospheric diffusion is ultimately accomplished by the wind induced movement of pollutants, but the character of the source of pollution requires that this action of the wind be taken into account in different ways. These sources can be conveniently grouped into three classes: point sources, line sources, and area sources. In practice, the first two classes must be further divided into instantaneous and continuous sources.

The instantaneous point source is essentially a "puff" of material created or ejected in a relatively short time, as by a nuclear explosion, the sudden rupture of a chlorine tank, or

the bursting of a tear-gas shell. The wind of immediate importance is, of course, that occurring at the place and time at which the pollutant is created. Since the wind is highly variable, the initial direction of movement of the puff is also variable and difficult to predict; a soap-bubble pipe and five minutes' close observation of the initial travel of successive bubbles will convincingly demonstrate the difficulty of predicting the exact trajectory of the next bubble. In addition, dilution of a puff source is a very strong function of time after its release. At first, the small-scale fluctuations of the wind cause it to grow rather slowly and the larger-scale wind variations simply carry it along on erratic paths. But as the puff grows, larger-scale motions can get a "hold" on it to tear it apart and dilute it more rapidly. Thus, the unique feature of the instantaneous point source is its increasing dispersion rate with time, hence, the necessity to consider successively larger scales of meterorological phenomena in calculating its spread.

Continuous point sources (the smoke plume from a factory chimney, the pall from a burning dump) are the most familiar, the most conspicuous, and the most studied of all pollution sources. The meteorology of the continuous source must take into account the time changes of the wind at the point of emission. The behavior of a plume from a factory chimney is very much like that of water from a hose being played back and forth across a lawn. It is evident that if the hose is steady, the same area will be continually exposed to the water. But if the hose (wind) moves back and forth in an arc, the water (pollution) will be distributed over a wider area, hence the concentration will be less. For a truly continuous source, there are other changes of great importance - primarily the diurnal and seasonal cycles.

The isolated line source is less common, and therefore, of less general interest, with two important exceptions - heavily traveled highways, and the swath of chemicals emitted by crop-dusting apparatus. In both these examples, if the line of pollutant is uniform and is long enough, the dispersion of the pollution must be attained in only two dimensions, along the wind and in the vertical. If the line source is a continuous one, as might be the case of a freeway in rush hours, spreading in the downwind direction becomes ineffective (at a particular downwind location), so that only the vertical dimension is left to provide dilution. This behavior of the continuous line source has been exploited by meteorologists in field experiments with controlled tracers to permit the detailed study of vertical diffusion, uncomplicated by effects in the other two coordinates.

The area source can vary enormously in size. It may be distributed over several square miles, as in an industrial park, over tens or hundreds of square miles, as in a city, or over thousands of square miles, exemplified by the almost continuous strip city (the "megalopolis" or "megapolitan area") along the eastern seaboard of the United States. These area sources usually include combinations of all the single-source configurations.

A large city will include many thousands of home chimneys, thousands of factories and shops, hundreds of miles of streets, open dumps, burning leaves, evaporating fumes from gasoline storage or from cleaning plants and paint factories, and everywhere the automobile. The weather problem of the city area source becomes, in the aggregate, quite different from that of a single source. Here we are concerned not with the increasing rate of wind dispersion with increasing scale, or with the behavior of wind with time at a single point, but rather with the replenishment rate of the air over the city. We must consider the total movement of a large volume of air as it "ventilates" the city. Anything that reduces this ventilation rate, whether it be the confining effect of surrounding mountains or the reduced velocities of a slow-moving anticyclone, is of concern.

In the construction of cities man has modified the weather as will be discussed in more detail in Section 4.2.6. The volume of effluent injected into the air has reduced the solar radiation. The absorption characteristics of cement and asphalt instead of grass and trees create urban "heat islands." These effects must be considered in the meteorology of urban air pollution. The urban heat island effect is discussed in more detail in Section 3.9

The atmosphere disperses pollutants because it is in constant mostion, and this motion is always turbulent to some degree. There is, as yet, no fully accepted definition of turbulence, but empirically it can be described as random (three-dimensional) flow. The understanding of turbulent diffusion in the atmosphere has progressed largely through empirical treatments of controlled tracer experiments. The current tendency is to deal with turbulence through statistical concepts derived from aerodynamics and fluid dynamics, in contrast to earlier theories which centered around a virtual-diffusivity concept. In the practical application of computing pollution concentrations, the common practice is to employ the statistical method for distances to perhaps 150 kilometers (93 miles) from the source, and equations based on virtual-diffusivity ("K") theory for longer distances, particularly for calculations on a hemispheric or global scale.

Vertical Turbulent Diffusion

To all intents and purposes rapid atmospheric diffusion in the vertical is always bounded: on the bottom by the surface of the earth and at the top by the tropopause. The tropopause - the demarcation between the troposphere, where temperature decreases with altitude, and the stratosphere, where the temperature is relatively constant or increases with altitude - is lowest over the poles, at about 5 miles, and highest in the tropics, at about 12 miles. The full depth of the troposphere is available for vertical dispersion. However, utilization of this total vertical dimension can take place at very different rates, depending on the thermally driven vertical wind. These rates are

intimately related to the vertical temperature profile. On the average (and if we neglect the effects of the phase change of water in the air), enhanced turbulence is associated with a drop in temperature with height of $10^{\circ}C$ per kilometer ($29^{\circ}F$ per mile) or greater (this is the dry adiabatic rate as discussed in Section 4.2.3). If the temperature change with height is at a lesser rate, turbulence tends to be decreased, and if the temperature increases with height (an "inversion"), turbulence is very much reduced.

The temperature profiles particularly over land, show a large diurnal variation as seen in Figure 4.2-1. Shortly after sunrise, the heating of the land surface by the sun results in rapid warming of the air near the surface; the reduced density of this air causes it to rise rapidly. Cooler air from aloft replaces the rising air "bubble," to be warmed and rise in turn. This vigorous vertical interchange creates a "super-adiabatic" lapse rate - a temperature decrease of more than $29^{\circ}F$ per vertical mile - and vertical displacements are accelerated. The depth of this well-mixed layer depends on the intensity of solar radiation and the radiation characteristics of the underlying surface. Over the deserts, this vigorous mixing may extend well above 2 miles, while over forested lake country, the layer may be only from three to seven hundred feet thick. Obviously, this effect is highly dependent on season; in winter, the lesser insolation and unfavorable radiation characteristics of snow cover greatly inhibit vertical turbulence.

In contrast, with clear or partly cloudy skies the temperature profile at night is drastically changed by the rapid radiational cooling of the ground and the subsequent cooling of the layers of air near the surface. This creates an "inversion" of the daytime temperature profile, since there is now an increase in temperature with height. In such a situation the density differences rapidly dampen out vertical motions, which tends to reduce vertical turbulence, and stabilize the atmosphere.

Two other temperature configurations, on very different scales, have important effects on vertical turbulence and the dilution of air pollution. At the smaller end of the scale, the heat capacity of urban areas and, to a lesser extent, the heat generated by fuel consumption act to modify the temperature profile. The effect is most evident at night, when the heat stored by day in the buildings and streets warms the air and prevents the formation of the surface-based temperature inversions typical of rural areas. Over cities, it is rare to find inversions in the lowest 300 feet; the city influence is usually evident 700 to 1000 feet above the surface. The effect is a function of city size and building density, but not enough observations are yet available to provide any precise quantitative relations. Although the effect even for the largest cities is probably insignificant above three thousand feet, this locally produced vertical mixing is quite important. Pollution, instead

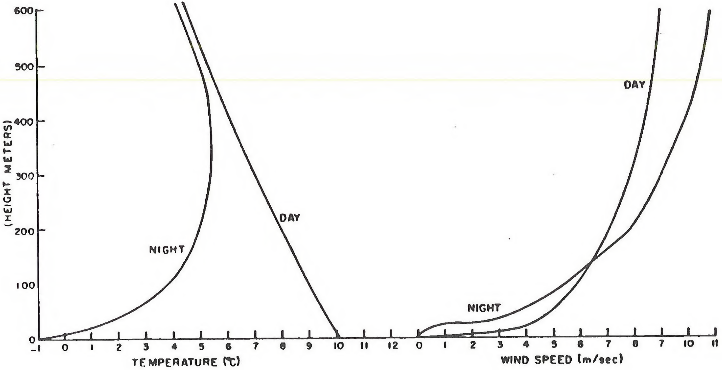


Figure 4.2-1

Diurnal Variation of Temperature and Wind Speed

of being confined to a narrow layer near the height of emission, perhaps only 300 feet in thickness, can be freely diluted in more than double the volume of air, the concentrations being reduced by a similar factor.

On a much larger scale the temperature profile can be changed over thousands of square miles by the action of large-scale weather systems. In traveling storm systems (cyclones), the increased pressure gradients and resulting high winds, together with the inflow of air into the storm, create relatively good vertical mixing conditions. On the other hand, the flat pressure patterns, slower movement, and slow outflow of surface air in high-pressure cells (anticyclones) result in much less favorable vertical mixing. This is primarily due to the gradual subsidence of the air aloft as it descends to replace the outflow at the surface. During this descent, the air warms adiabatically, and eventually there is created a temperature inversion aloft, inhibiting the upward mixing of pollution above the inversion level. As the anticyclone matures and persists, this subsidence inversion may lower to very near the ground and persist for the duration of the particular weather pattern.

Horizontal Turbulent Diffusion

The most important difference between the vertical and horizontal dimensions of diffusion is that of scale. In the vertical, rapid diffusion is limited to about 10 kilometers (6 miles). But in the horizontal, the entire surface of the globe is eventually available. Even when the total depth of the troposphere is considered, the horizontal scale is larger by at least three orders of magnitude, and the difference, say during a nocturnal inversion which might restrict the vertical diffusion to within a hundred feet, is even greater since the lateral turbulence is reduced less than the vertical component. Mechanically produced horizontal turbulence is, on a percentage basis, much less important than the thermal effects; its effects are of about the same order of magnitude as the vertical mechanical effects.

The thermally produced horizontal turbulence is not so neatly related to horizontal temperature gradients as vertical turbulence is to the vertical temperature profile. The horizontal temperature differences create horizontal pressure fields, which in turn drive the horizontal winds. These are acted upon by the earth's rotation (the Coriolis effect) and by surface friction, so that there is not such a thing as a truly steady-state wind near the surface of the earth. Wind speeds may vary from nearly zero near the surface at night in an anticyclone, to 200 miles per hour under the driving force of the intense pressure gradient of a hurricane. The importance of this variation, even though in air pollution we are concerned with much more modest ranges, is that for continuous sources the concentration is inversely proportional to the wind speed.

The variation of turbulence in the lateral direction is perhaps the most important factor of all and certainly one of the most interesting. In practice, this can best be represented by the changes in horizontal wind direction illustrated in Figure 4.2-2. Within a few minutes, the wind may fluctuate rapidly through 90 degrees or more. Over a few hours it may shift, still with much short-period variability, through 180 degrees, and in the course of a month it will have changed through 360 degrees numerous times. Over the seasons, preferred directional patterns will be established depending upon latitude and large-scale pressure patterns. These patterns may be very stable over many years, and thus establish the wind climatology of a particular location.

The emitted pollution travels with this ever-varying wind. The high-frequency fluctuations spread out the pollutant, and the relatively steady "average" direction carries it off - for example, toward a suburb or a business district. A gradual turning of direction transports material toward new targets and gives a respite to the previous ones. Every few days the cycle is repeated, and over the years the prevailing winds can create semipermanent patterns of pollutions downwind from factories or cities.

4.2.2 Prevailing Winds

Wind speed and direction play a fundamental role in the dispersion of airborne contaminants. The following paragraphs discuss wind speed and direction and other wind characteristics and their associated impact on local and regional dispersion potential.

Mean wind direction has a basic impact on air pollutant levels. If the wind direction is representative of the height at which the pollutant is released, the mean direction will be indicative of the direciton of travel of the pollutants. In meteorology, it is conventional to consider the wind direction as the direction from which the wind blows, therefore, a northwest wind will move pollutants to the southeast of the source.

The effect of wind speed is two-fold. The wind speed will determine the travel time from a source to a given receptor, e.g., if a receptor is located 1000 meters (3281 ft) downwind from a source and the wind speed is 5 meters/second (16.4 ft/sec), it will take 260 seconds for the pollutants to travel from the source to the receptor. The other effect of wind speed is a dilution in the downwind direction. If a continuous source is emitting a certain pollutant at the rate of 10 grams/second (~1.3 lbs/min) and the wind speed is 1 meter/second (~2.2 mph) then in a downwind length of the plume of 1 meter (3.3 feet) will be contained 10 grams (~0.02 lbs) of pollutant since 1 meter (3.3 feet) of air moves past the source each second. Next, consider that the conditions of emission are the same but the wind speed is 5 meters/second (~11 mph). In this case, since 5 meters (16.4

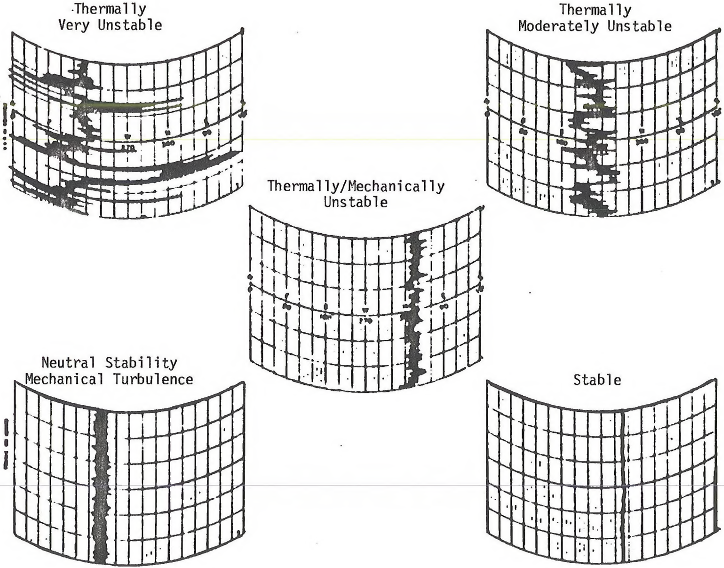


Figure 4.2-2

Gustiness Classification

feet) of air moves past the source each second, each meter of plume length contains 2 grams (~0.04 lbs) of pollutant. Therefore, it can be seen that the dilution of air pollutants released form a source is proportional to the wind speed. This may be restated in another form: The concentration of air pollutants is inversely proportional to wind speed.

Wind speed is generally found to increase with height above the ground and wind direction to veer (turn clockwise) with height (in the northern hemisphere at extratropical latitudes) due to the effects of friction with the earth's surface. The amount of these increases in speed and veering in direction are quite variable, and to a great degree, related to the roughness of the surface and the stability of the atmosphere.

In the preceding paragraphs, consideration of only the mean speed and direction of wind has been made. Of course, there are deviations from these means. There are velocity components in all directions creating vertical motions as well as horizontal ones. These random motions of widely different scales and periods are essentially responsible for the movement and diffusion of pollutants about the mean downwind path. These motions, commonly called eddys, are considered as atmospheric turbulence. If the scale of a turbulent motion, i.e., the size of an eddy, is larger than the size of the pollutant plume in its vicinity, the eddy will move that portion of the plume. If an eddy is smaller than the plume, its effect will be to diffuse or spread out the plume. This diffusion caused by the eddy motion is widely variable, but even when this duffusion is at the minimum, it is roughly three orders of magnitude greater than the diffusion by molecular action alone.

During the daytime, solar heating causes turbulence to be at a maximum and vertical motions to be strongest. This causes the maximum amount of momentum exchange between various levels in the atmosphere. Because of this, the variation of wind speed with height is least during the daytime. Also, the amount of veering with height is least (on the order of 15^{o} to 20^{o} over average terrain). The thickness of the friction layer will also be greatest during the day due to the vertical exchange.

At night, the vertical motions are least and the effect of friction is not felt through as deep a layer as during the day. The surface speed over average terrain is much less than the free atmosphere wind (on the order of 1/4 to 1/3 that of the 1000 meter (3281 feet) wind) and the amount of veering with height may be on the order of 40^{o} to 45^{o}. Figure 4.2-3 shows the diurnal variation of wind speed at two different levels on a meteorological tower (Singer and Raynor, 1957).

Wind data are generally only available in terms of speed and direction. Turbulence data are considerably more sophisticated and are generally only available as a result of specialized, site-specific data gathering programs. Such data are only

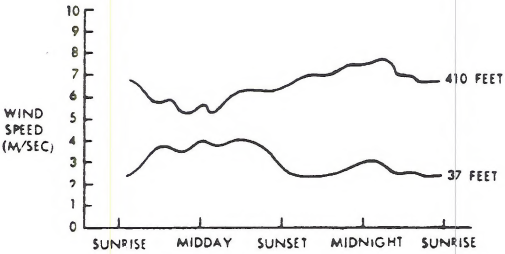


Figure 4.2-3
Diurnal Variations in Wind Speed
As a Function of Height (1)

(1) Data from Meteorological Tower
Brookhaven National Laboratory
April 1950-March 1952

used in very detailed modeling analyses. The bulk of the modeling analyses conducted for the air pollution industry require only basic wind data for speed and direction. This latter type of data are generally summarized in the form of wind roses. These may be viewed in Figure 4.4-1.

A wind rose is defined in the Glossary of Meteorology as, "Any one of a class of diagrams designed to show the distribution of wind direction experienced at a given location over a considerable period; it thus shows the prevailing wind direction. The most common form consists of a circle from which eight or sixteen lines emanate, one for each compass point. The length of each line is proportional to the frequency of wind from that direction; and the frequency of calm conditions is entered in the center. Many variations exist. Some indicate the range of wind speeds from each direction; some relate wind direction with other weather occurrences." Wind roses may be constructed for data from a given time period such as a particular month or may be for a particular time of day or season from a number of years of data. In constructing or interpreting wind roses, it is necessary to keep in mind the meteorological convention that wind direction refers to the direction from which the wind is blowing. A line or bar extending to the north on a wind rose indicates the frequency of winds blowing from the north, not the frequency of winds blowing toward the north. Some of the specialized wind roses that may be constructed are precipitation wind roses, stability wind roses, and pollution wind roses. The latter two require additional data than are generally available at standard Weather Bureau stations. An informative article on the history and variants of wind roses has been published by Court (1963).

Prior to January 1964, the surface wind direction was reported by U.S. Weather Bureau stations as one of the 16 directional points corresponding to the mariner's compass card or compass rose, on which each direciton is equivalent to a 22 1/2 sector of a 360^{o} circle. Table 4.2-1 illustrates, in the form of a frequency table of wind direction versus wind speed groups, the data essential to the development of a 16-point wind rose. It is an example of summaries of hourly observations published monthly until January 1964 in the Local Climatological Data (LCD) Supplement. Frequencies are totaled by direction and wind speed group. A quick look at this wind rose indicates the highest directional frequency is from the ENE and the highest speed frequency is the 8 to 12 mph column. Average speeds have been computed for each direction.

When wind roses are employed to summarize climatological data involving long periods of record, percentage frequencies are favored over numerical totals for tabular presentation since the number of observations in any one cell can become quite large. Moreover, wind rose diagrams can be drafted directly from tabular data if percentages are available. Table 4.2-2 presents 10 years of hourly wind data observed at New Orleans Moisant International

Table 4.2-1

A Typical Tabular 16 Point Wind Rose

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED										AVERAGE SPEED	
	KNOTS 0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	40 Over	TOTAL	KNOTS	M.P.H.
	M.P.H. 0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 Over			
N	8	13	15	18	12	3				69	10.8	12.4
NNE	1	16	28	30	7	1				83	10.2	11.7
NE	7	34	36	5						82	6.7	7.7
ENE	11	51	46	5						113	6.3	7.3
E	6	19	14	4						43	6.4	7.3
ESE	4	15	13	3						35	6.5	7.5
SE	1	13	4	2						20	6.3	7.2
SSE	2	6	20	11						39	8.3	9.6
S	3	11	21	10	1					46	8.2	9.4
SSW	3	9	9	9	4					34	9.3	10.6
SW	1	8	7							16	6.3	7.2
WSW		4	3	1						8	6.9	7.9
W	1	5	7							13	6.5	7.4
WNW	1	16	6	1						24	6.0	6.9
NW	2	3	6	1						12	7.2	8.2
NNW	1	11	29	26	6	1				74	10.6	12.2
CALM	33									33	0.0	0.0
TOTAL	85	234	264	126	30	5				744	7.7	8.9

Table 4.2-2

Sample Long-Term Wind Rose Data for

New Orleans, Louisiana

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED										M.P.H.
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	+	1	2	3	1	+	+	+		7	13.9
NNE	+	1	2	3	1	+				6	12.8
NE	+	2	3	3	+	+				8	11.0
ENE	+	2	4	2	+	+	+			8	9.9
E	+	2	3	1	+					6	9.1
ESE	+	1	1	1						3	8.4
SE	+	2	2	+	+					5	7.8
SSE	+	3	3	1	+	+		+		9	9.9
S	+	3	4	2	+	+				10	9.8
SSW	+	1	3	2	1	+				7	12.0
SW	+	1	1	+	+	+				3	8.6
WSW	+	1	1	+	+	+	+			2	10.7
W	+	1	1	1	+	+	+			2	11.8
WNW	+	1	1	1	+	+	+			3	12.5
NW	+	1	1	1	1	+	+			5	13.9
NNW	+	1	2	2	2	1	+	+		8	14.7
CALM	8									8	
TOTAL	11	22	34	23	7	2	+	+		100	10.3

Airport during January for the years 1951 through 1960, as published in the "Decennial Census of United States Climate." This 10-year summary of meteorological data is compiled for most U.S. Weather Bureau first order stations.

On January 1, 1964, the U.S. Weather Bureau changed the wind direction reporting procedure from 16 points to 36 - 10° intervals. Table 4.2-3 is the result; a 36-point wind rose. Since 36 cannot be divided by 16 there is no way of grouping 36 points into 16 points and there is no easy way of combining wind data if the wind rose summaries include both 16-point and 36-point wind direction observations. For this and other reasons, the 36-point wind rose was dropped after 1964. A few air quality models such as CRSTER require 36 point wind rose data, and for such an application, 1964 data must be used.

This report will present wind roses using a very simplistic format. The frequency of the wind direction for each of the 16 cardinal directions is plotted and lines are drawn connecting each directional frequency (See Section 4.4.1)

4.2.3 Atmospheric Stability

Whether the atmosphere has a tendency to enhance or to dampen out vertical motions is important to atmospheric processes which produce weather as well as to the effects upon air pollutant dispersion. The stability of the atmosphere is highly dependent upon the vertical distribution of temperature with height.

<u>Adiabatic Lapse Rate</u>

Due to the decrease of pressure with height, a parcel of air lifted to higher altitude will encounter decreased pressure and expand and, in undergoing this expansion, will cool. If this expansion takes place without loss or gain of heat to the parcel, the change is adiabatic. Similarly, a parcel of air forced downward in the atmosphere, will encounter higher pressures, contract, and become warmer. This rate of cooling with lifting, or heating with descent is the dry adiabatic lapse rate and equals 5.4°F per 1000 feet or approximately 1°C per 100 meters. This process lapse rate is the rate of heating or cooling of any descending or rising parcel of air in the atmosphere and should not be confused with the existing temperature variation with height at any one time, i.e., the environmental lapse rate.

<u>Environmental or Prevailing Lapse Rate</u>

The manner in which temperature changes with height at any one time is the environmental or prevailing lapse rate. This is principally a function of the temperature of the air and of the surface over which it is moving and the rate of exchange of heat between the two. For example, during clear days in midsummer the ground is rapidly heated by solar radiation. This in

Table 4.2-3

A Typical Tabular 36 Point Wind Rose

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED										AVERAGE SPEED	
	KNOTS 0-3	4-6	7-10	11-16	17-22	22-27	28-33	34-40	41 OVER	TOTAL	KNOTS	M.P.H.
	M.P.H. 0-3	4-7	8-12	13-18	19-24	25-31	32-39	40-46	47 OVER			
01	3	5	2	3						13	6.9	8.0
02	7	9	8							24	5.3	6.0
03	3	9	7							19	5.4	6.2
04	7	22	2	1						32	5.3	6.1
05	9	15	7	4						35	5.9	6.8
06	11	27	17	6						61	6.2	7.1
07	4	27	16	3						50	6.2	7.1
08	3	7	13	3						26	7.2	8.3
09	1	9	6	5						21	7.7	8.8
10	5	9	4							18	5.1	5.8
11	5	11	5	1						22	5.8	5.5
12	5	5	4							14	5.9	5.7
13	2	4	3							9	6.0	6.9
14	5	7	6							18	5.2	6.0
15	1	7	5		1					14	7.1	8.1
16	1	8	4							13	5.9	6.8
17	1	6	4							11	6.2	7.1
18		6	9	6						21	8.8	10.1
19	2	2	3							7	5.7	6.6
20	3	5	7	5						15	7.1	5.1
21	2	2	3	1						8	6.6	7.6
22	2	2	5	6						15	8.6	9.9
23	4	2	7	3						16	7.3	8.3
24	5	2	2	1						10	5.3	6.1
25	3	1		1						5	5.0	5.8
26	2	3	4	4						13	7.6	8.8
27	2	6	1							9	5.0	5.8
28	3	5	4							12	5.5	6.3
29		2	9	7						18	9.7	11.2
30		3	4	7						14	10.1	11.7
31	2	2	2	12						18	10.3	11.9
32	2	3	12	10	1					28	9.9	11.4
33	1	7	9	13						30	9.4	10.8
34	1	2	11	11						25	9.6	11.0
35	3	1	1	2						7	6.7	7.7
36	4	6	8	2						20	7.0	8.1
00	53									53	0.0	0.0
TOTAL	167	249	209	117	2					744	6.4	7.4

turn, provides for rapid heating of the layers of the atmoshpere nearest the surface. Further aloft, however, the atmospheric temperature will remain relatively unchanged. Conversely, at night, radiation from the earth's surface cools the ground and the air adjacent to it, resulting in only slight decrease of temperature with height, and in cases when the surface cooling is great enough, temperature may increase with height. This atmosphere is considered stable.

If the temperature decreases more rapidly with height than the dry adiabatic lapse rate, the air has a super-adiabatic or strong lapse rate and the air is unstable. If a parcel of air is forced upwards it will cool at the adiabatic lapse rate, but will still be warmer than the environmental air. Thus it will continue to rise. Similarly, a parcel which is forced downward will heat dry adiabatically but will remain cooler than the environment and will continue to sink.

For environmental lapse rates that decrease with height at a rate less than the dry adiabatic lapse (sub-adiabatic or weak lapse) a lifted parcel will be cooler than the environment and will sink; likewise, a descending parcel will be warmer than the environment and will rise. Figure 4.2-4 shows the relative relation between the environmental lapse rates of super-adiabatic (strong lapse), sub-adiabatic (weak lapse), isothermal, and inversion with the dry adiabatic process lapse rate presented as dashed lines.

Lifting motions which promote cooling at dry adiabatic lapse rates may be caused by upslope motion over mountains or warmer air rising over a colder air masses. Descending motion (subsidence) may occur to compensate for the lateral spreading of air in high pressure areas.

Classification Schemes

The dispersive power of the atmosphere can be categorized into seven classes, labeled stability categories, in accordance with a method proposed by Pasquill (1962) and modified by Gifford (1961) and Markee (1966). Pasquill's first three classes, A, B, and C, range from extreme to slight instability. Class D represents neutral or well-mixed conditions, while E and F represent slight and moderate stability, respectively. Dispersive power decreases with progression through these classes. Markee (1966) has further divided the original class F into classes F and G, with G representing extreme stability. For the purpose of simplifying the presentation, classes A, B, and C have been combined, in some instances, to form one category called unstable. Similarly, class D will be referred to as the neutral category, and classes E, F, and G together form the stable category.

The stability of the atmosphere is determined by various methods using numerous forms of meteorological data. A frequently used means of assessing ambient atmospheric stability is

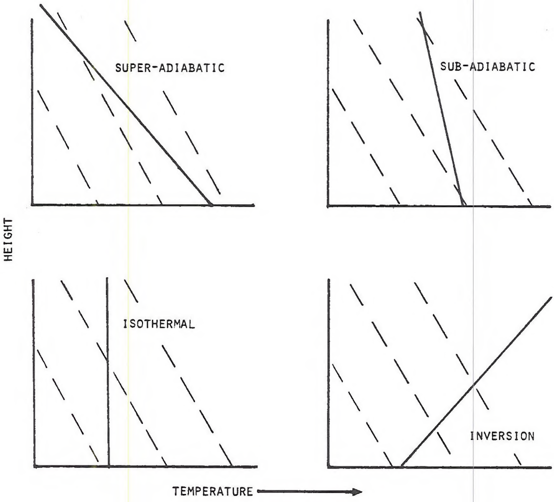


Figure 4.2-4

Types of Temperature Structure with Height Related to the Dry Adiabatic Process Lapse Rate

through the measurement of changes in atmospheric temperature with altitude ($\Delta T/\Delta Z$) above an area in question. This is accomplished by probing the atmosphere with specialized temperature sensors mounted on aircraft, balloons, or on tall meteorological towers.

Figure 4.2-5 graphically illustrates the $\Delta T/\Delta Z$ criteria for stable, neutral and unstable conditions. Temperature profile "A" is classified as unstable because its profile slope is less than the dry adiabatic lapse rate ($\Delta T/\Delta Z$ = -9.8^{o}C/km) (-28.4^{o} F/mi). A neutral atmosphere is one that exhibits a temperature profile approximately equivalent to the dry adiabatic lapse rate. Stable atmospheres have $\Delta T/\Delta Z$ values greater than -9.8^{o}C/km (-28.4^{o}F/mi). An atmospheric inversion, a special case of a stable atmosphere, occurs when the ambient $\Delta T/\Delta Z$ value increases with altitude rather than decreases.

Unstable conditions generally occur during periods of high positive net radiation (toward the earth's surface) and low wind speeds. Stable conditions require high negative net radiation (away from the earth's surface) and low wind speeds, while neutral conditions generally develop because of cloudy skies and/or high winds speeds. This more general method of defining atmospheric stability is the one most frequently used in the air pollution industry today.

The NCC in Asheville, North Carolina, has devised a somewhat subjective technique based upon available measurements of surface wind speed coupled with the strength of incoming solar insolation as defined by such parameters as sky cover, time of day and latitude. This technique is summarized in Table 4.2-4 and is used by the NCC to develop the STAR (STability ARay) data that is used extensively in this document. One interesting aspect of this technique results from the heavy dependance upon solar insolation. By this definition, stable conditions can occur only at night, unstable conditions only during the day, while neutral conditions can occur during either night or day.

The Influence Of Vertical Temperature Structure Upon Plume Behavior

The manner in which stack effluents diffuse is primarily a function of the stability of the atmosphere. Church (1949) has typified the behavior of smoke plumes into five classes. Hewson (1960) has added a sixth class, taking into account inversions aloft (Inversions will be discussed in more detail in section 4.2.4). Figure 4.2-6 depicts each class and the appropriate dispersion characteristics for an idealized chimney. The Pasquill stability classes are also noted.

Looping

Looping occurs with a super-adiabatic lapse rate. Large thermal eddies are developed in the unstable air and high concentrations may be brought to the ground for short time intervals.

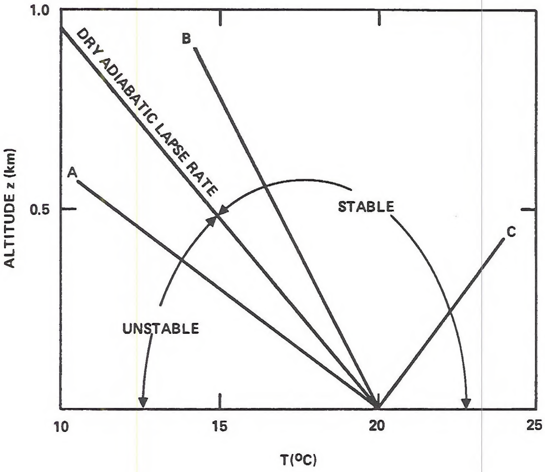


Figure 4.2-5
Temperature Profiles which are Examples of
(A) Unstable, (B) Stable, and (C) Very Stable Inversion
Lapse Rates in a Dry Atmosphere

Table 4.2-4

Key to Stability Categories

Surface Wind Speed (at 10 m) m/sec	Isolation			Night	
	Strong	Moderate	Slight	Thinly Overcast or $\geq$ 4/8 Low Cloud	$\leq$ 3/8 Cloud
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

The neutral category, D, should be assumed for overcast conditions during day or night.

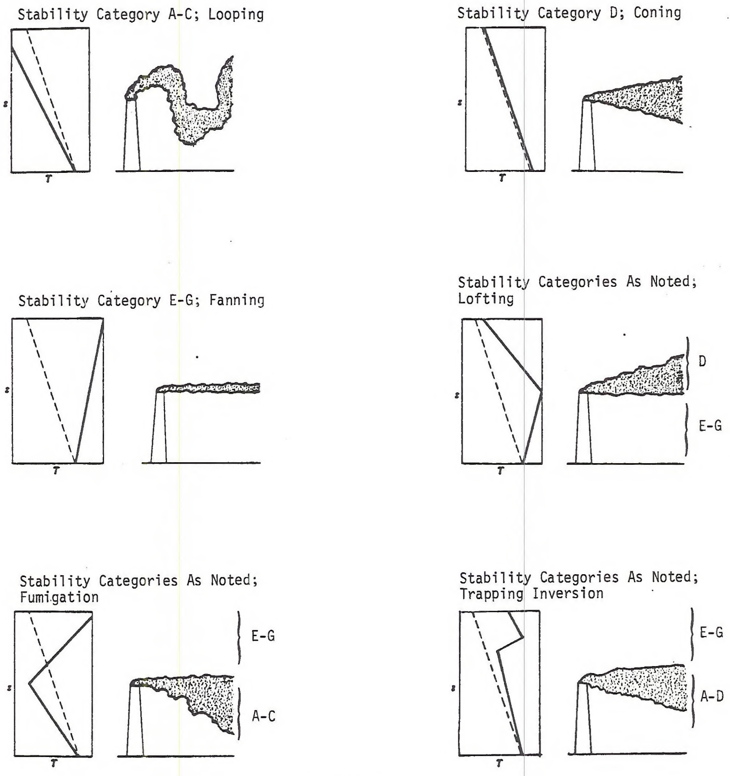


Figure 4.2-6

Typical Plume Behavior*

* Plume behavior influenced by the temperature lapse rate above and below the release height. The dashed lines in the profiles are the adiabatic lapse rates, included for reference, while the solid lines indicate the actual lapse rate. The Pasquill stability categories are also provided.

Diffusion is good, however, when considering longer time periods. The super-adiabatic conditions which cause looping occur only with light winds and strong solar heating. Cloudiness or high winds will prevent such unstable conditions from forming.

Coning

With vertical temperature gradients between dry adiabatic and isothermal, slight instability occurs with both horizontal and vertical mixing but not as intense as in the looping situation. The plume tends to be cone shaped hence the name coning. The plume reaches the ground at greater distances from the source than with the looping plume. Coning is prevalent on cloudy or windy days or nights. Diffusion equations are more successful in calculating concentrations for this type of plume than for any other.

Fanning

If the temperature increases upward as in an inversion, the air is stable and vertical turbulence is suppressed. Horizontal mixing is not as great as in coning but still occurs. The plume will, therefore, spread horizontally but little if any vertically. Since the winds are usually light, the plume will also meander in the horizontal. Plume concentrations are high but, little effluent from elevated sources reaches the ground, except when the inversion is broken due to surface heating, or terrain effects at the elevation of the plume. Clear skies with light winds during the night are favorable conditions for fanning.

Lofting

Lofting occurs when there is a super-adiabatic layer above a surface inversion. With this condition, diffusion upward is rapid, but downward, diffusion does not penetrate the inversion and so is dampened out. Under these conditions, gases will not reach the surface but particles with appreciable settling velocities will drop through the inversion. Near sunset on a clear evening in open country is most favorable time for lofting. Lofting is generally a transition situation and, as the inversion deepens, is replaced by fanning.

Fumigation

As solar heating increases, the lower layers are heated and a super-adiabatic lapse rate occurs through a continuously deeper layer. When the layer is deep enough to reach the fanning plume, thermal turbulence will bring high concentrations to the ground along the full length of the plume. This is favored by clear skies and light winds and is apt to occur more frequently in summer due to increased heating.

Another type of fumigation may occur in the early evening over cities. Heat sources and mechanical turbulence due to surface roughness causes an adiabatic condition to develop in the lower layers of the stable air moving into the city from non-urban areas where radiation inversions are already forming. This causes a fumigation until the city loses enough heat so that the adiabatic condition is dimished.

Trapping

When an inversion occurs aloft, such as a frontal or subsidence inversion, a plume released beneath the inversion will be trapped beneath it. Even if the diffusion is good beneath the inversion, such as with a coning plume, the limit to upward diffusion will increase concentrations in the plume and at ground level.

4.2.4 Mixing Heights and Inversions

An adiabatic diagram can be used to plot the distribution of temperature and moisture, with height in the atmosphere. This is of considerable use to the meteorologist in determining freezing levels, condensation levels of moisture in lifted air parcels, forecasting cloud bases and tops, determining stability for cloud formation and thunderstorm forecasting. Moisture levels are especially important to the air pollution meteorologist as moisture works as a catalyst for the formation of secondary pollutants such as sulfates and nitrates and high moisture content will serve to reduce visibility.

To the air pollution meteorologist a sounding plotted on an adiabatic chart is principally used to determine the large scale stability of the atmosphere over a given location. The principal source of atmospheric measurements that may be plotted on the adiabatic chart are the radiosonde measurements taken twice daily: 0000 GMT (1900 EST) and 1200 GMT (0700 EST) at about 66 stations in the contiguous United States. The method of obtaining these soundings is to release into the atmosphere a balloon borne instrument package having sensors for temperature, pressure, and humidity and a radio transmitter for relaying this information to the ground station. This information on the upper air is collected primarily to serve the purpose of forecasting and aviation briefing. Consequently, the information is not as detailed in the lowest 5000 feet as an air pollution meteorologist desires. Also, in air pollution meteorology, it is desirable to have information more frequently than 12 hours apart. In spite of these deficiencies for air pollution purposes, the soundings from the radiosonde network will give indications of the stability of the atmosphere. On an adiabatic chart, temperature is plotted on a linear scale against pressure on a logarithmic scale. A temperature sounding may be plotted by locating each significant level reported by the temperature and pressure given for that level. The plotted points may then be connected by straight lines to give the temperature sounding.

As indicated in Section 4.2.3, the stability of a portion of the sounding may be compared with the dry adiabatic lapse rate. If the temperature decreases more rapidly than the dry adiabats through a layer, this layer is super-adiabatic and quite unstable. If the temperature decreases, but at a rate less than the dry adiabatic lapse rate, the layer is sub-adiabatic and is more stable than super-adiabatic. If the temperature increases with height, it is an inversion.

Inversions with bases at ground level are generally radiation inversions caused by the cooling of the earth's surface and the adjacent air. However, there may also be advection inversions formed by the air's passage over a relatively cold surface. These two types of surface based inversions generally cannot be distinguished by inspection of the sounding plotted on an adiabatic diagram. A surface based inversion on an afternoon sounding is more apt to be an advection inversion.

There are two general classifications of inversions with bases above the ground: frontal inversions and subsidence inversions. Both of these, however, can also be ground based.

Frontal inversions are discontinuities in the temperature profile due to the transition between cold air below and warm air aloft. Frontal inversions usually are accompanied by increases in moisture through the inversion. Subsidence inversions are caused by the sinking motion above high pressure areas and generally have rapidly decreasing humidities above the base of the inversion.

Surveys of the meteorological aspects of air pollution are often concerned with the extent of horizontal and vertical mixing. A quantity referred to as the mixing depth is quite useful when considering dilution of pollutants in the vertical. The usual method of estimating mixing depths is to consider the stability as portrayed on a temperature sounding remembering that unstable lapse rates favor vertical mixing and stable lapse rates restrict vertical motion. The mixing depth is generally the height above the ground to which a super or dry-adiabatic lapse rate is maintained as depicted in Figure 4.2-7.

4.2.5 Influence of Topography on Transport and Diffusion

In many cases, the transport and diffusion of air pollutants is complicated by terrain features. Most large urban areas are located either in river valleys or on the shores of lakes or oceans. Both of these features alter meteorological conditions.

<u>Valley Effects</u>

- <u>Channeling</u>
  Although the more extreme effects of a valley location occur when the general flow is light, valleys tend to channel the general flow along the valley axis resulting in a bi-directional wind frequency distribution.

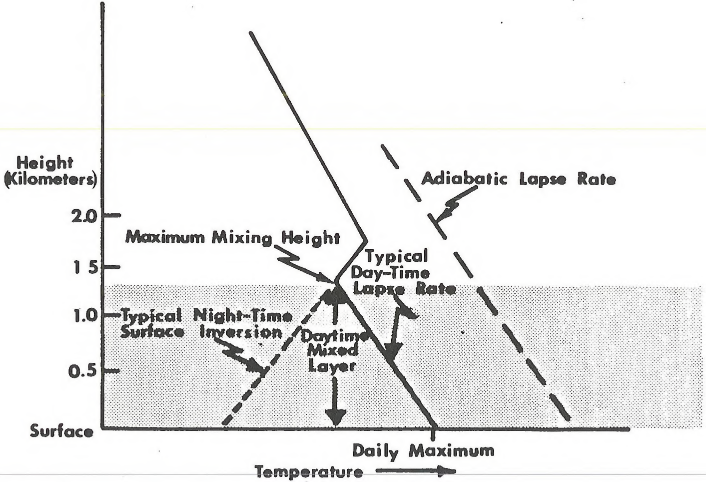


Figure 4.2-7

Calculation of Maximum Mixing Height

- Slope and Valley Winds

When the general wind flow is light and skies are clear, the differences in rates of heating and cooling of various portions of the valley floor and sides cause slight density and pressure differences resulting in small circulations. During the evening hours radiational heat from the earth's surface and the resultant cooling of the ground and air adjacent to the ground causes density changes. The air at point A (Figure 4.2-8) is more dense than at point B since point A is nearer the radiating surface. Therefore, the more dense air at point A tends to flow in the general direction of B and similarly at other points along the slope. This is the slope wind.

If the slope in Figure 4.2-8 is a side of a valley as in Figure 4.2-9, the cold air moving down the slopes will tend to drain into the valley floor and deepen with time, intensifying the radiation inversion that would form even without the addition of cold air. Any pollutants that are emitted into this air, because of the inversion structure, will have very limited vertical motion.

If, in addition, the valley floor has some slope, the cold air will have a tendency to move downhill along the valley axis. This is usually referred to as the valley wind (See Figure 4.2-10). Because of the necessity of some accumulation of cold air from slope winds, the onset of the valley wind usually lags several hours behind the onset of the slope wind.

The steeper the slopes of the valley, the stronger the slope wind can become. Vegetation will tend to reduce the effect by impeding the flow and also restricting the amount of radiation that can take place.

On a clear day with the light winds, the heating of the valley may cause upslope and upvalley winds. However, the occurance of upslope and upvalley winds is not as frequent nor as strong as the downslope and downvalley winds, principally due to the fact that downslope and downvalley winds, because of their density, hug the surfaces over which they travel. Flow in complex valley systems where several valleys merge at angles or slopes varies, usually require special observations to determine flow under various meteorologic conditions.

- Inversions Aloft

The trapping of air pollutants beneath inversions aloft is also a problem encountered in valleys. Two types of inversions: warm frontal and subsidence inversions are

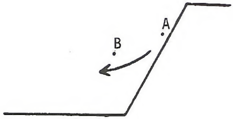


Figure 4.2-8

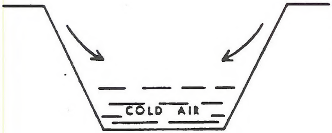


Figure 4.2-9

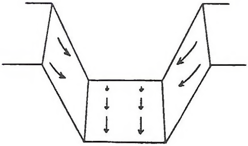


Figure 4.2-10

Valley Wind Circulations

of particular concern since they are usually slow moving. High concentrations may occur particularly if the layer of air beneath the inversion becomes unstable enough to mix pollutants from elevated sources to ground level (Hewson et al, 1961).

Shoreline Winds

The differences in heating and cooling of land and water surfaces and the air above them, result in the setting up of circulations if the general flow is light, and in the modification of thermal characteristics, and consequently, the diffusive abilities of the lower layers of the atmosphere when a general flow occurs.

- Sea or Lake Breeze
  On summer days with clear skies and light winds, the heating of the land surface adjacent to a large lake or the ocean is much more rapid than the heating of the body of water. This results in a temperature difference, and consequently, a density and pressure difference between the air just above the land surface and the air over the water. Because of the pressure gradient forces, a local circulation is set up with wind from the water toward the land, There is usually some upward motion over the land and subsidence over the water accompanying the sea breeze (Estoque, 1961). There may result a weak transport from land to water aloft completing a cellular structure (See Figure 4.2-11).

  In cases where a strong lake breeze occurs, air from quite some distance out over the water may be brought toward the land and, due to Coriolis forces acting over the long trajectory, the resulting flow will become nearly parallel to the shoreline (Sutton, 1953). This occurs just after the sea breeze is strongest and results in decreasing the flow normal to the coastline and the subsequent breakdown of the sea breeze.

- Land Breeze
  At night, the rapid radiational cooling of the land causes lower temperatures above the land surface than over the water. Thus a reverse flow, the land breeze, may result. The land breeze does not usually achieve as high a velocity as the lake breeze, and is usually shallower than the sea or lake breeze.

  Of course, any wind flow, because of the large scale pressure pattern, will alter the local circulation and the flow will be the resultant of the two effects. Usually, a light general flow is enough to overshadow the effects of land and sea breezes.

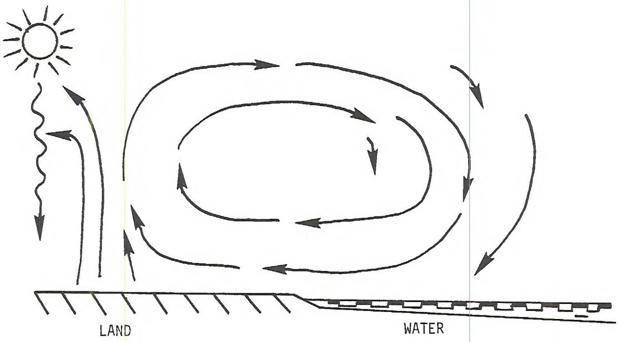


Figure 4.2-11
Idealized Sea Breeze Regime

Modification of Thermal Structure by Bodies of Water

At different seasons of the year and also different times of the day, the temperature of bodies of water and adjacent land surfaces may be quite different. For example, during the late spring, large bodies of water are still quite cold relative to adjacent land surfaces, and during mid-afternoon this difference is greatest due to the more rapid heating of the land surface. If the general flow in the area is such that the wind has a lengthly trajectory over the water and is blowing toward the shore, an interesting modification of the temperature structure takes place. Because of the passage over the cold water surface, the air will have an inversion in the lower layer as it reaches the shoreline. Any air pollutants released into this inversion will essentially have the characteristics of a fanning plume. As the air passes over the warm land, a strong lapse rate replaces the inversion near the surface. The depth of this layer will deepen as the air moves over more heated land surface. If the layer becomes deep enough to reach the fanning effluent from an elevated source, fumigation will occur and continue as long as the temperature difference between land and water is maintained and flow from water to land occurs. At greater distances from the shoreline, the inversion will be eliminated and plume looping will occur. On the other hand, if the source is high enough to be above the lake induced inversion, lofting of the plume would occur until enough distance, and consequently, enough heating takes place to eliminate the inversion.

Figure 4.2-12 indicates the difference in vertical temperature structure that occurs in the above example, and Figure 4.2-13 indicates the effect this will have on the plume characteristics of an elevated shoreline source.

At other times when the water is warmer than the land surface (late fall), offshore flow will result in fumigation over the water.

Influence of Hills

The influence of hills upon transport and diffusion depends upon a number of factors. Whether the source is on the windward or lee side of the hill or ridge is important. A smooth hill will only slightly alter the flow, while one with sharp ridges will cause turbulent eddies to form. The stability of the atmosphere will affect the overall influence of hills. During stable conditions, the air will tend to flow around obstructions. Under unstable conditions, the tendency is for air to move over obstructions.

When a source is located upwind of a hill or ridge, the pollutants may come in contact with the facing slope, particularly under stable conditions. If the ridge is quite rough, induced turbulence may cause mixing down to the slope even when

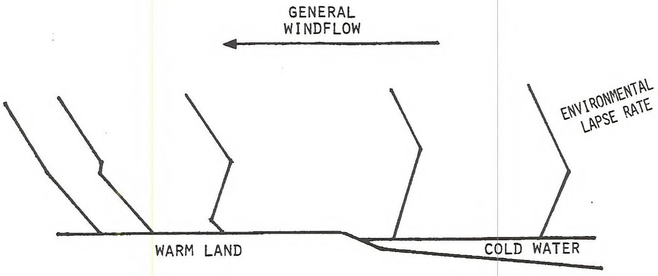


Figure 4.2-12
Modification of Vertical Temperature Structure Due to Flow Over Differently Heated Surfaces

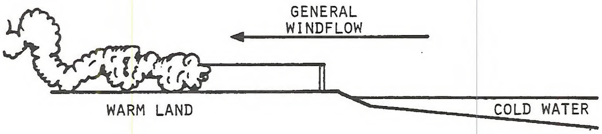


Figure 4.2-13
Effect Upon Plume Characteristics of Flow Over Differently Heated Surfaces

the general flow is over the ridge. Wind tunnel studies or field trials with constant level balloons may be desirable to determine the flow under given circumstances.

For a source downwind form a hill or ridge, lee eddies will generally cause considerable downwash of the effleunt near the source. If turbulent flow is induced by the hillside, diffusion will be increased but high concentrations very near the stack will result periodically, due to the downwash. Examples may be viewed in Figure 4.2-14

Persistence of Fog

The occurence of fog, together with very stable atmospheric conditions above the earth's surface, has been noted in several air pollution episodes, particularly in Donora, Pennsylvania, in 1948. Under clear skies at night, the ground loses much heat because of outgoing radiation and the air in contact with the ground will cool. If, in such cases the air is sufficiently humid, cooling will bring the air to the saturation point and a fog will form. This is the mechanism which produces radiation fog and is quite common in valley locations. The top of a layer of fog will radiate essentially as a black body and cool further, thus forming an inversion layer directly above the fog. As the earth continues to radiate in the infrared, the fog droplets absorb nearly all this heat since the droplet size distribution is similar to the wavelengths of the radiation. Theory and observation have shown that when the top of a fog layer radiates during the night, the interior of the layer will become more unstable with time. Increased vertical mixing will occur from below but will be capped by the inversion. Since the air is saturated, an unstable lapse rate will exist if the temperature decrease with height is greater than the moist or pseudo-adiabatic lapse rate ($3^{o}F$ per 1000 ft.), rather than the dry adiabatic lapse rate of ($5.4^{o}F$ per 1000 ft.)

Thus, pollutants that are emitted aloft into an originally stable layer at night, and would not normally reach the ground until morning, may be contained within a fog layer as the night progresses and be brought to the ground in relatively high concentrations.

After daybreak, fog will often persist for several hours or even the entire day under full sunlight due to the high reflectivity of the top layer. The reflectivity or albedo of thick fogs averages 50% and can be as high as 85%. This delays and lessens the heating of the ground and subsequent evaporation of the fog droplets. An unstable lapse rate may occur above the fog layer, but due to a lack of surface heating, an inversion will often occur within the layer. If high concentrations of particulate pollutants are present, it may be difficult to determine just when the fog has dissipated since particulates scatter and absorb visible light very well and the visibility may remain quite restricted.

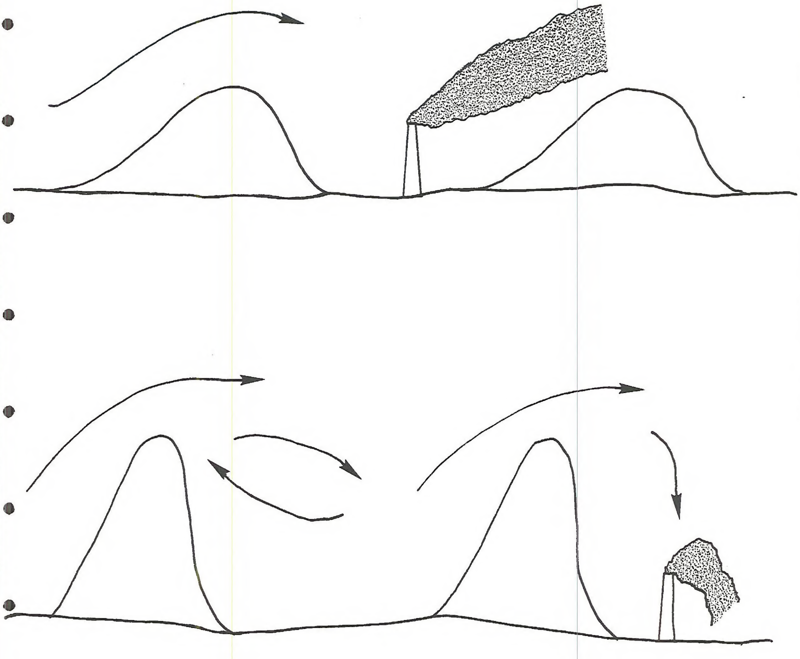


Figure 4.2-14
Influence of Hills Upon Transport and Diffusion

Figure 4.2-15 illustrates how fog can persist in valley situations and maintain a lid on vertical dispersion. This situation often occurs over the Central Valley portions of the Folsom District during winter. The conditions, known locally as "Tule Fog" can persist for days resulting in reduced visibilities and poor ambient air quality.

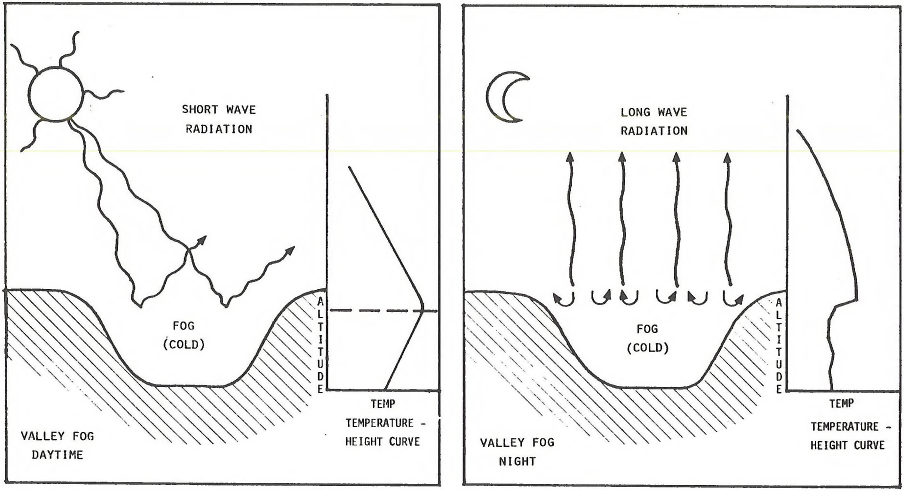


Figure 4.2-15

Persistence of Fog and Corresponding Temperature Profiles During the Day and Night

4.3 DATA SOURCES

Numerous sources of dispersion meteorological data are available in the Folsom District. Many of these data are available in unreduced or partially reduced form and have not been utilized in the present analysis. However, a knowledge of their availability is desirable in instances where they may be of value for future more detailed site-specific analyses.

For the present, the data base has been limited to sources of data readily available, reduced, and in summarized form which cover a period of 5 years or more. As discussed earlier key parameters of interest include wind speed and wind direction, atmospheric stability, mixing heights, temperature inversions, and winds aloft. Primary sources of such complete data include first order National Weather Service (NWS) stations and special interest (usually private industry) stations. Figure 4.3-1 provides an illustration of the locations of key meteorological stations located in the Folsom District which have been used to establish a regional assessment of dispersion meteorology. Other reference materials and data sources are also discussed in the text in instances where they add additional insight into the dispersion meteorology for specific areas.

The following sections are based upon three key sets of data. These include (1) STability ARray (STAR) data as available from the National Climatic Center (NCC) in Asheville, North Carolina, (2) dispersion meteorological data from industry sources and (3) NWS and California Air Resources Board (CARB) upper air temperature and wind data. STAR data provide the joint frequency distribution of wind speed, wind direction and atmospheric stability class on a monthly, seasonal and annual basis. Within the Folsom District, STAR data for Stockton, Monterey and Fresno have been used for the present analysis. In addition, data from Bishop, California have also been used even though this station lies just outside the Folsom District, in the Bakersfield District. It has been included in an effort to provide an indication of conditions on the eastern side of the Sierra Nevada. STAR data are available for other stations in the district as indicated on the study map. The data used in this report were chosen to provide a representative and cost-effective cross-section of the dispersion meteorology of the District.

Similar data are also collected by private industry, particularly in the licensing of nuclear facilities. Pacific Gas & Electric (PGE) in San Francisco routinely collects data at Diablo Canyon, Buttes (near Oroville), Stanislaus (east of Modesto) and Willows (west of Oroville). With the exception of the Stanislaus site, all of these locations are outside of the Folsom District; however, in each instance, the stations are sufficiently close to provide additional useful information relative to dispersion conditions in the northern and southwest coastal portions of the District. These data, like the available STAR data from NWS stations, provide joint frequency distributions of

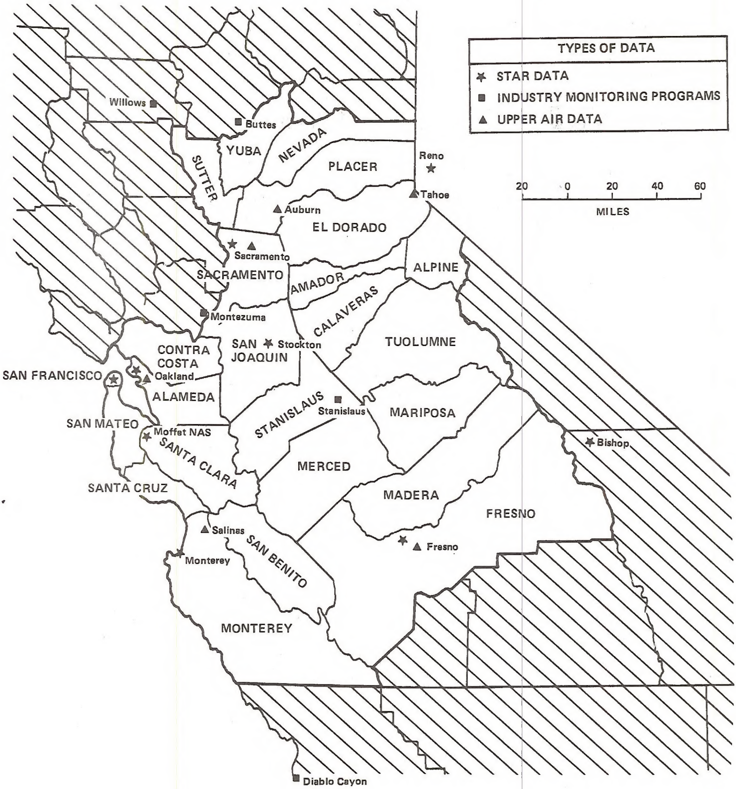


Figure 4.3-1
Sources of Dispersion Meteorological Data
Used in the Folsom District Analysis

wind speed, wind direction and atmospheric stability class. Table 4.3-1 provides a summary of the available dispersion meteorological data from NWS and private industry sources in or near the Folsom District. All of these data have been utilized in the present analysis as appropriate.

Upper air wind and temperature data are also available for certain portions of the Folsom District. The Oakland NWS station is the only regular first order station routinely taking temperature and wind aloft data on a twice daily basis. These data have been utilized by Holzworth (1972) to provide data on inversion types and frequencies, as well as mixing heights and mean wind speeds through the mixing layer. The CARB has also conducted various programs for the collection and summarization of temperature sounding and/or pilot balloon (winds aloft) release data at selected stations throughout the state. In the Folsom District, these include Sacramento, Salinas, Merced and Fresno. The availability of these data permits finer resolution of mixing heights and inversions in the Central Valley. The available NWS data would be insufficient to clearly describe these parameters in the Folsom District.

Table 4.3-1

Available Dispersion Meteorological Data in the Folsom District

Station Name	County Location	Data Description	Period of Data Base
Fresno AP (NCC)	Fresno	Wind speed, wind direction and atmospheric stability (24 obs./day)	1/60-12/64
Stockton (NCC)	San Joaquin	Wind speed, wind direction and atmospheric stability (8 obs./day)	1/72-12/76
Monterey (NCC)	Monterey	Wind speed, wind direction and atmospheric stability (24 obs./day)	1/59-12/63
Bishop (NCC)	Inyo	Wind speed, wind direction and atmospheric stability (0600-1900 PST)	1/60-12/64
Sacramento (NCC)	Sacramento	Seasonal and annual wind distributions by Pasquill stability classes (8 obs./day)	1/66-12/70
Oakland (NCC)	Alameda	Daily mixing depth and average wind speed data Average wind speed through the mixing depth Inversion study	1/60-12/64 1/60-12/64 1/60-12/64
Salinas (CARB)	Monterey	Vertical temperature sounding and mixing height summaries	10/71-4/74
Sacramento (CARB)	Sacramento	Vertical temperature soundings and mixing height summaries	9/71-2/74
Fresno (CARB)	Fresno	Vertical temperature soundings and mixing height summaries Morning aircraft soundings	10/71-3/74 5/72-12/77
Auburn (CARB)	Placer	Inversion summary tables	May to Nov. 1946 & 1947
Tahoe (CARB)	El Dorado	Raw data of vertical temperature profiles	Aug. 1978
Montezuma (PGE)	Solano	Wind speed and wind direction summaries with stability class breakdown	5/70-4/71
Diablo Canyon (PGE)	San Luis Obispo	Wind speed and wind direction summaries with stability class breakdown	5/73-4/78
Butte (PGE)	Butte	Wind speed and wind direction summaries with stability class breakdown	10/77-9/73
Willows (PGE)	Glenn	Wind speed and wind direction summaries with stability class breakdown	10/77-9/78
Stanislaus (PGE)	Stanislaus	Wind speed and wind direction summaries with stability class breakdown	6/75-5/78

4.4 PREVAILING WINDS

The characterization of prevailing surface winds and winds aloft is essential in the development of an understanding of the dispersion meteorology of the Folsom District. This section provides analyses that are designed to identify specific characteristics of the prevailing winds. These analyses include:

- Wind Roses
- Diurnal Wind Distributions
- Wind Speed Distributions
- Wind Persistence Analyses
- Trajectory Analyses
- Winds Aloft

The prevailing winds define the net regional transport characteristics for pollutants in a given geographical area. An understanding of the physical behavior of air flow in and out of a particular area of interest provides insight as to the fate of air pollutants.

4.4.1 Wind Roses

Wind roses provide a graphical representation of the frequency of occurrence of winds from each of the 16 cardinal directions for specified averaging periods. This subsection discusses the prevailing winds using wind rose analyses on a seasonal and annual basis.

Regional wind characteristics throughout the Folsom District are discussed in considerable detail in Section 3.4. This includes a summary of monthly and annual average wind speeds and prevailing wind directions throughout the study area. Also, a Folsom District study map with numerous superimposed annual wind roses was provided in order to depict the air flow on a regional scale. The discussion provided in this section is designed to summarize prevailing air flow characteristics in terms of a dispersion analyses for subsequent use in pollutant impact studies.

Annual

Annual wind rose diagrams for selected key stations in the district are provided in Figures 4.4-1 through 4.4-8. Monterey and San Francisco wind roses describe wind conditions characteristic of coastal areas. Stockton, Sacramento and Fresno wind roses are indicative of prevailing flow for the Central Valley locations. The Donner Summit, Blue Canyon and Bishop wind roses characterize air flow patterns on all sides of the Sierra Ridge line. Figure 4.4-9 provides a study map of the district, superimposed with several annual wind rose diagrams. This figure appeared in Section 3.4 but is presented here, as well, due to its importance in describing regional flow characteristics.

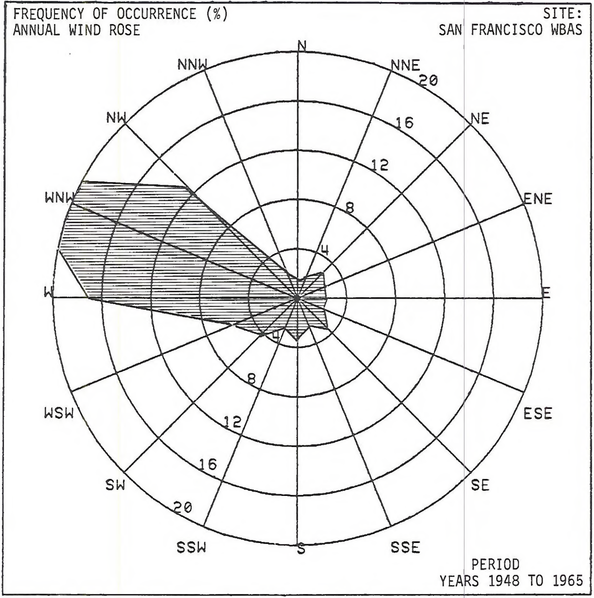


Figure 4.4-1
Annual Wind Rose for San Francisco

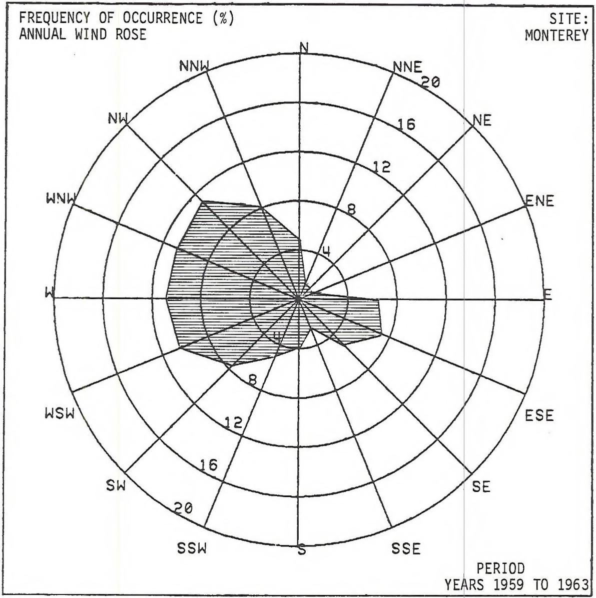


Figure 4.4-2
Annual Wind Rose for Monterey

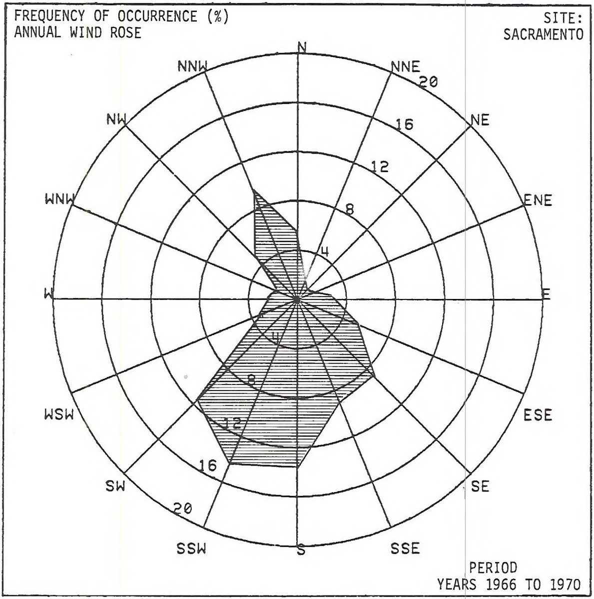


Figure 4.4-3
Annual Wind Rose for Sacramento

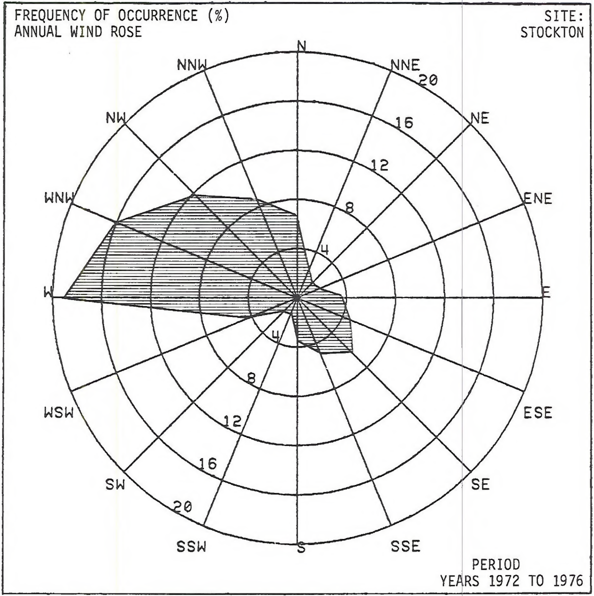


Figure 4.4-4
Annual Wind Rose for Stockton

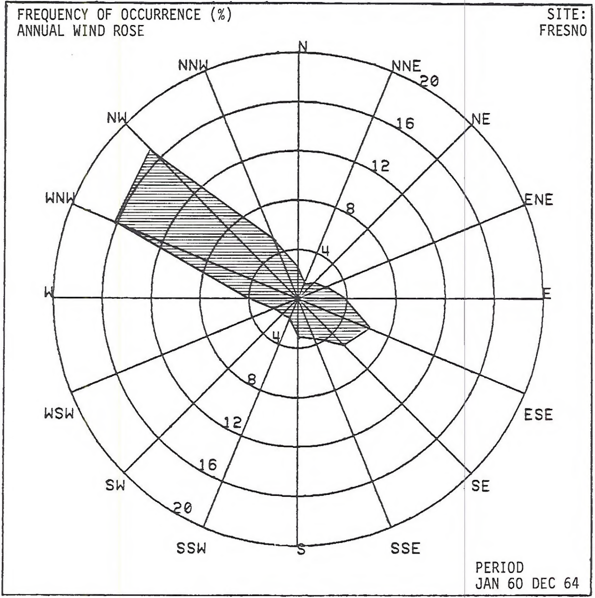


Figure 4.4-5
Annual Wind Rose for Fresno

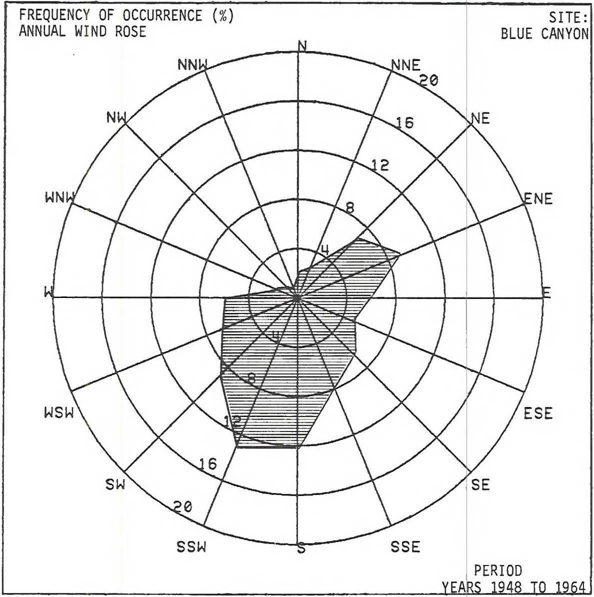


Figure 4.4-6
Annual Wind Rose for Blue Canyon

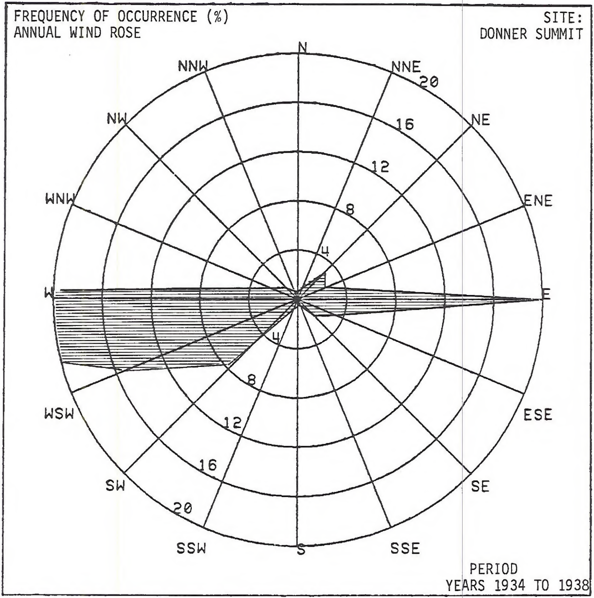


Figure 4.4-7
Annual Wind Rose for Donner Summit

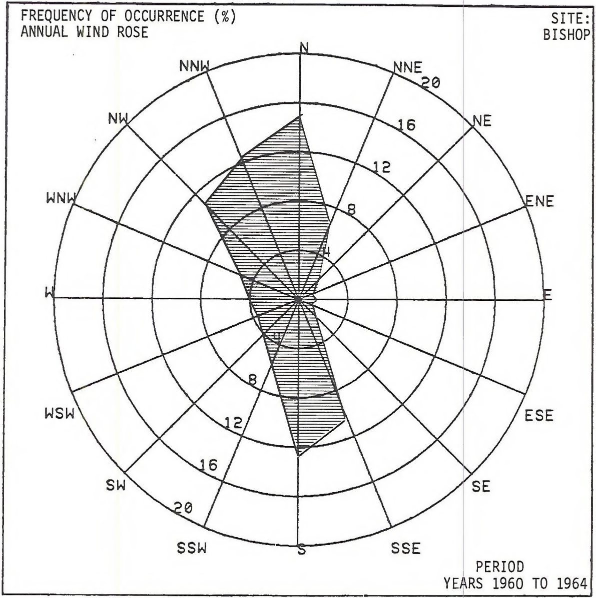


Figure 4.4-8
Annual Wind Rose for Bishop

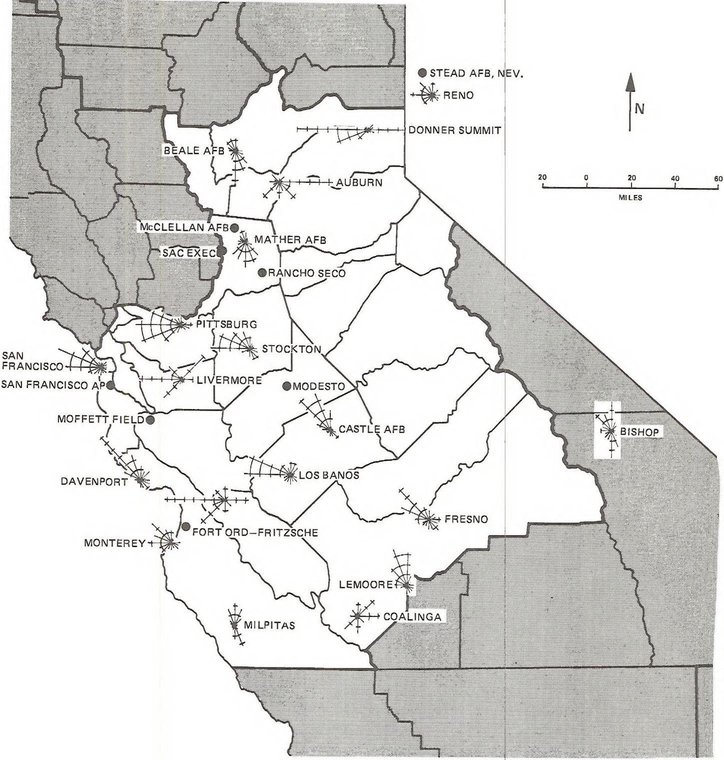


Figure 4.4-9
Annual Wind Roses for Selected Key Stations
in the Folsom District

Note: Each Division on the Roses is Equal to an Annual Frequency of 5%.

The annual wind roses for San Francisco and Monterey presented in Figures 4.4-1 and 4.4-2 indicate the preponderance of flow from the west and northwest at coastal locations. The wind rose for Monterey indicates a seconday maxima for winds from the east-southeast, representing drainage flow from higher terrain further inland. As indicated in Figure 4.4-9, terrain has considerable influence in determining the actual prefered direction for onshore flow at coastal sites such as Monterey. Actual flow in the more rugged areas of the coastal mountains can be significantly different than that observed at Monterey and San Francisco.

Annual wind roses for Sacramento, Stockton and Fresno are provided in Figures 4.4-3 through 4.4-5. Prevailing winds along a northwest-southeast axis are indicative of conditions in the Central Valley of California, with northwesterly flow dominating the distribution at all stations south of a line running from San Francisco eastward through Stockton. The figures illustrate that at Stockton, the wind is oriented more from a westerly direction when compared, for example, with Fresno. This indicates the proximity of the preferred entrance for flow into this area through the Carquinez Straits to the west and northwest of Stockton.

Stations in the northern third of the Central Valley portion of the Folsom District, experience a primary maximum for winds from the south and south-southeast reflecting the preferred route of inland flow through the Carquinez Straits turning northward into this portion of the Central Valley. Figure 4.4-9 provides a more detailed presentation of annual prevailing flow throughout the district.

Wind distributions along the Sierra Nevada are strongly influenced by local terrain features. Wind roses for Blue Canyon, Donner Summit and Bishop are provided in Figures 4.4-6 through 4.4-8. They illustrate the extreme diversity often experienced in mountain air flow. Blue Canyon is located on the western slopes of the Sierra Nevada, at an elevation of 5280 feet MSL. Air flow along the Sacramento Valley floor is channeled along the Bear River Valley and past Blue Canyon. Air flow that was once southerly along the valley floor is channeled along a more westerly direction at Blue Canyon. The Donner Summit wind rose depicts flow characteristic of crestline areas where the local channeling of air movement is minimal. As seen from Figure 4.4-7, a definite east-west wind direction distribution is prevalent for this area.

East of the Sierra, flow is again highly influenced by terrain considerations as it descends down the moutain slopes. This is evident from the Bishop wind rose presented in Figure 4.4-8. At Bishop, the terrain surrounding the Mono Valley distinctly influences the prevailing wind distribution.

Seasonal

Seasonal wind roses for Monterey, Stockton, Fresno, Sacramento and Bishop are provided in Figures 4.4-10 through 4.4-14.

The Fresno wind roses depicted in Figure 4.4-11 describe the seasonal distributions of winds in the San Joaquin Valley portion of the Folsom District. These distributions indicate the dominance of upvalley, northwesterly flow which reaches a maximum during spring and summer. A secondary maxima is evident for winds from the southeast and east-southeast particularly during fall and winter.

Further north, at Stockton, the preferred direction for modified, maritime flow is from the west and northwest with the maximum frequency of winds from these directions occurring during the summer months. A secondary maximum is observed for winds from the southeast quadrant which is recognized as the primary wind direction during the winter months.

Figure 4.4-13 illustrates the seasonal distributions of winds in the Sacramento Valley portion of the Folsom District. During spring, summer and fall, southwest and south-southwesterly flow dominate at Sacramento, while southeasterly winds are prevalent during the winter months. A secondary maximum occurs for north-northwesterly flow during all seasons. These drainage winds are most often observed during the winter season.

At Bishop, the seasonal differences in the prevailing winds mainly reflect local terrain considerations. As indicated by the annual wind rose, winds are aligned along the axis of the Mono Valley floor. Northerly winds occur most frequently during the winter months, while southerly to south-southeasterly flow reaches a maximum during summer and fall. Episodes of strong maritime flow, moving inland through the Central Valley, will tend to be oriented through mountain passes as it moves up and over the Sierra Nevada. These winds may reach stations such as Bishop, from either the north or south depending upon the preferred exit routes through the Sierra Nevada.

4.4.2 Diurnal Wind Distribution

The diurnal distribution of both wind speed and wind direction provides average values of these parameters as a function of the hour of the day. Such data provides useful additional information on the dispersion characteristics of a given geographical area. For example, the diurnal distribution of wind direction provides a good indication of when certain downwind areas could be impacted by sources of air pollutants. In addition, the diurnal distribution of wind speed provides an indication of the time of day when best dispersion conditions can be expected based upon average wind speeds and the associated degree of pollutant transport. This is important to know in activities such as prescribed fires.

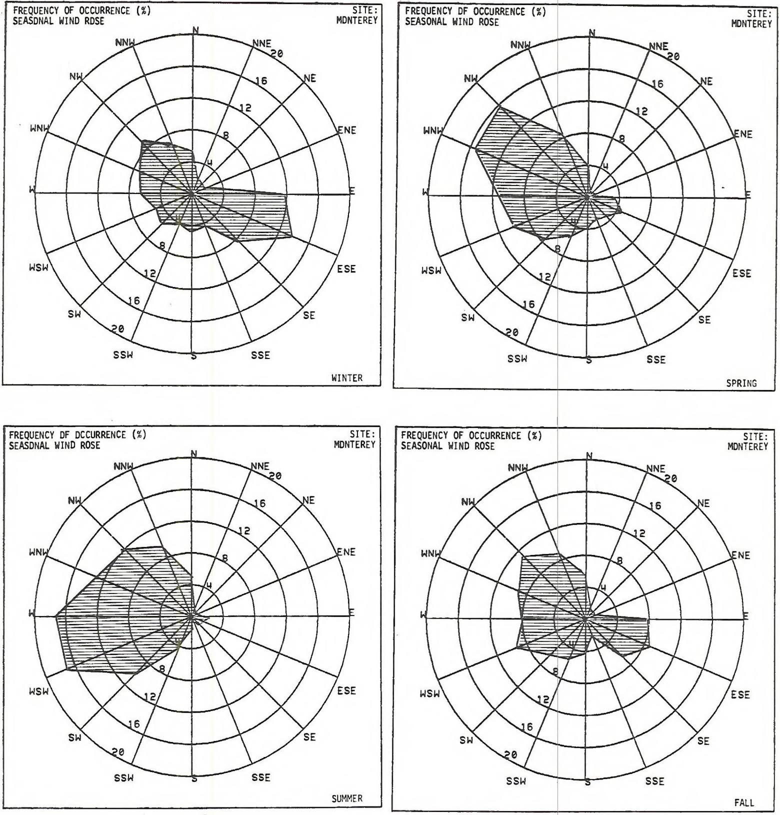


Figure 4.4-10
Seasonal Wind Roses for Monterey

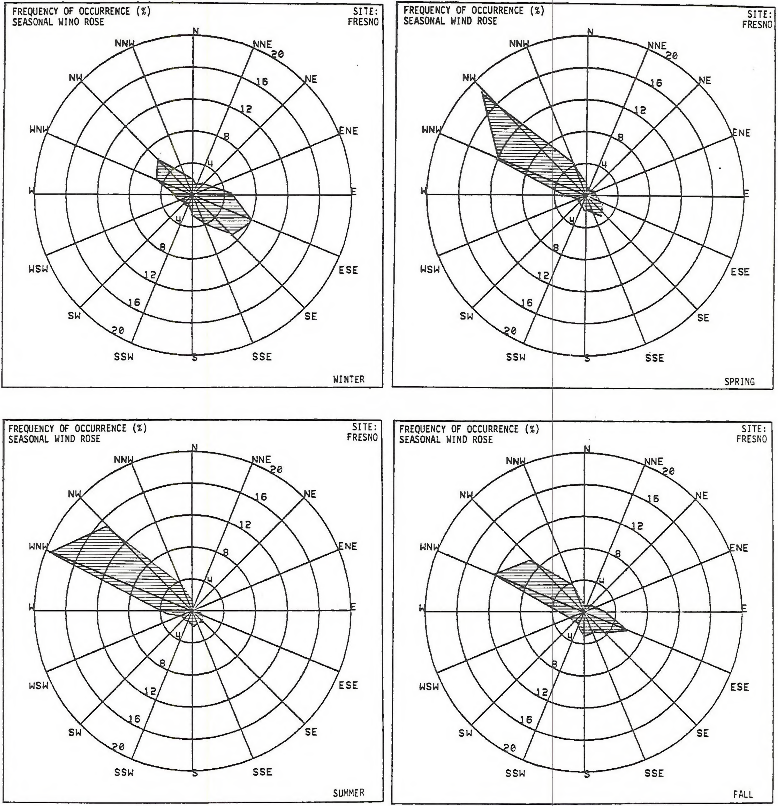


Figure 4.4-11
Seasonal Wind Roses for Fresno

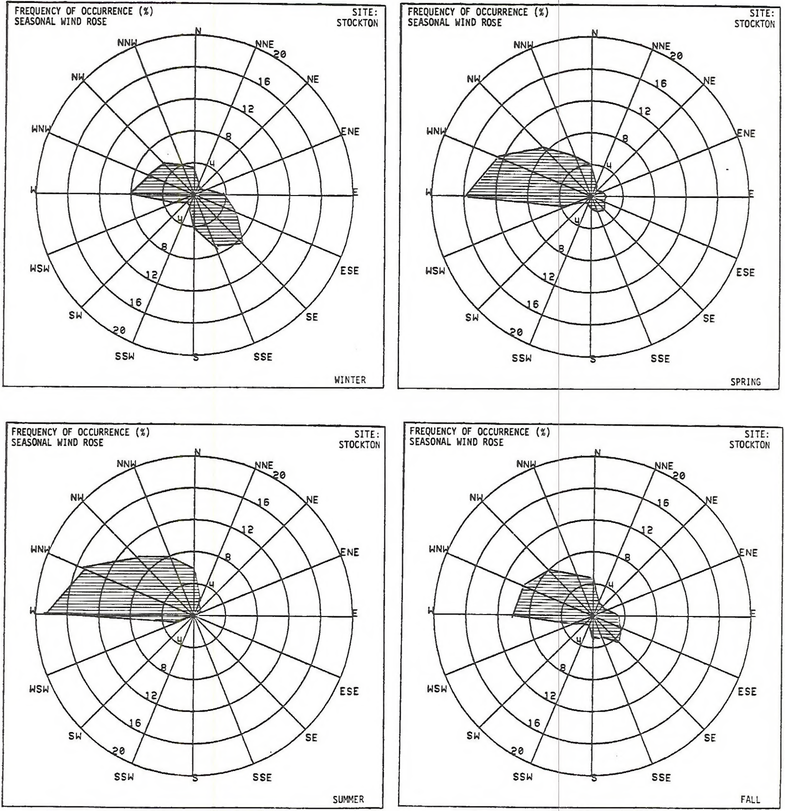


Figure 4.4-12
Seasonal Wind Roses for Stockton

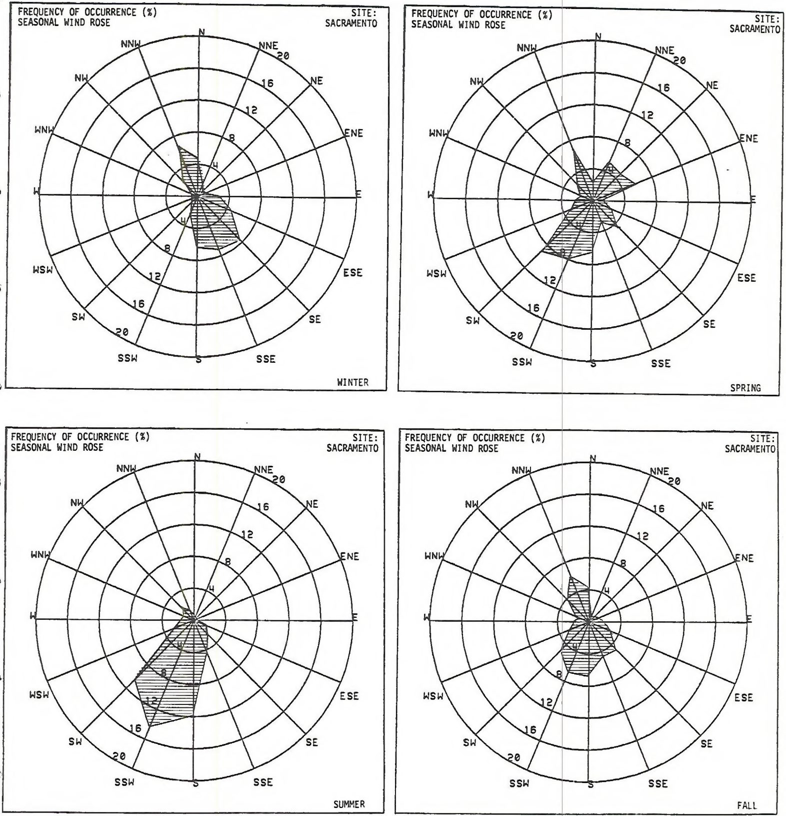


Figure 4.4-13
Seasonal Wind Roses for Sacramento

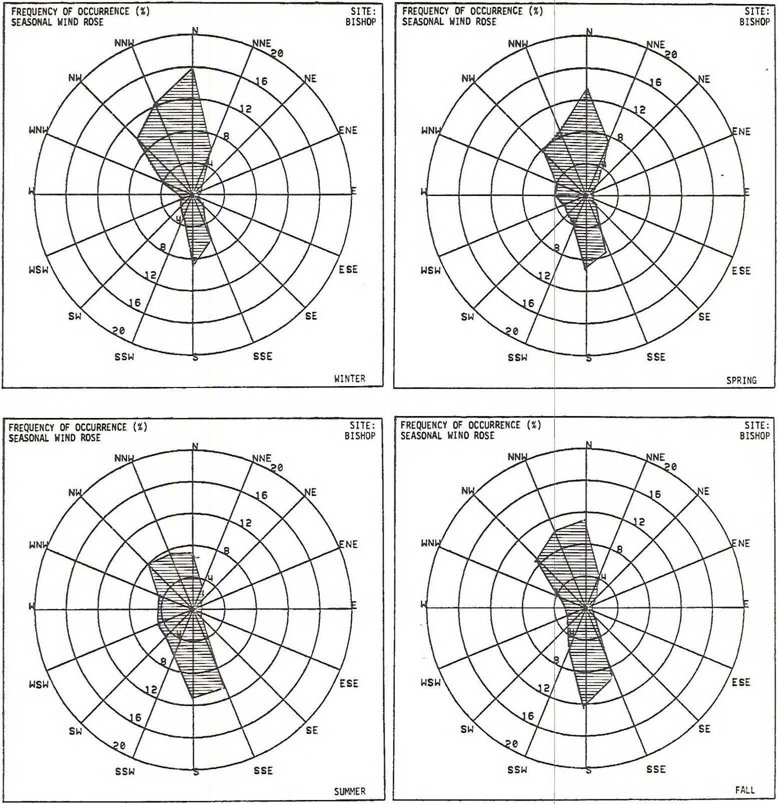


Figure 4.4-14
Seasonal Wind Roses for Bishop

Wind Direction

Figures 4.4-15 through 4.4-18 present the diurnal wind direction distribution for Monterey, Stockton, Fresno and Bishop. These data provide insight into the direction of the prevailing winds as a function of time of day. This information can be valuable to community and industrial planners concerned with the control of existing emission sources and the placement of new sources since they can be used to determine which specific areas in a region are most likely to be adversely impacted by pollutants throughout the day.

The diurnal wind direction distribution for Monterey shows a dominance of winds from the east-southeast from just after midnight until one or two hours after sunrise. This flow represents the nocturnal drainage of cool air from the nearby slopes of the Coast Range and from the Salinas Valley to the east. During the day, the flow shifts nearly 180° to the west and northwest as the sea-breeze regime develops in response to daytime inland surface heating. Towards sunset, as surface heating decreases, the drainage flow begins to take effect once again.

The marked variability in the daily wind direction at Monterey is quite different from that experienced at Stockton, where the daily distribution is comprised of winds from the west and west-northwest as indicated in Figure 4.4-16. Stockton is located just beyond the eastern end of the Carquinez Straits and during the day, Stockton receives flow moving eastward through the Straits under the influence of the sea breeze. At night, however, after the sea breeze has dissipated, west winds continue to persist at this location as nocturnal drainage flow from the west dominates.

The analysis for Fresno presented in Figure 4.4-17 shows a wind direction distribution similar to the Stockton analysis for most of the day. The Fresno data also show the effect of air movement through the Carquinez Straits into the San Joaquin Valley. Between noon and 0600 (Pacific Standard Time) PST, the wind at Fresno is either from the west-northwest or the northwest. This represents flow originating over the Pacific, moving through the Straits and flowing southward into the San Joaquin Valley. An abrupt change in the direction of flow is noted between 0600 and 1000 PST when the wind direction shifts to the southeast. This flow represents the drainage of cool air down the western slopes of the Sierra Nevada Mountains into the San Joaquin Valley. This flow does not begin until nearly sunrise because this is when the coldest temperatures are seen and the drainage winds become strong enough to degrade the prevailing westerly flow. The drainage flow will continue since the westward facing slopes of the Sierra Nevada Mountains do not start receiving solar radiation of sufficient intensity to dissipate the drainage flow regime until later in the morning.

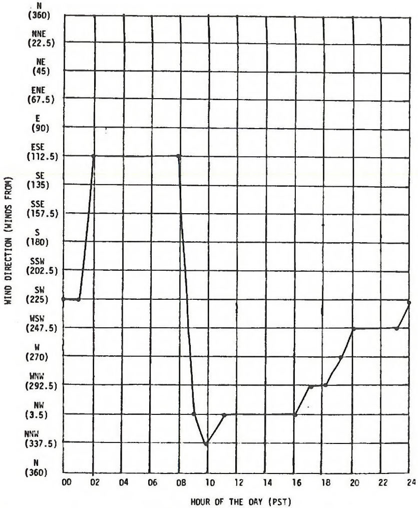


Figure 4.4-15

Diurnal Wind Direction Distribution at

Monterey, California (1958-1963)

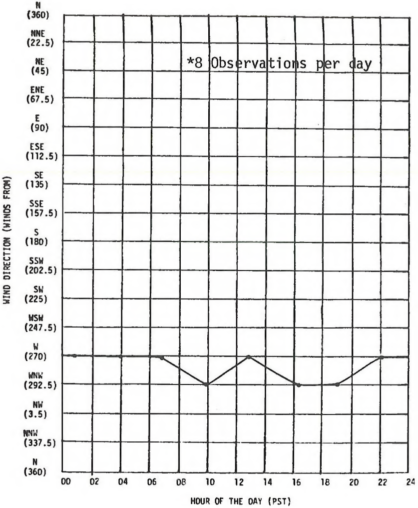


Figure 4.4-16

Diurnal Wind Direction Distribution at

Stockton, California (1972-1976)*

Note: Diurnal Wind Direction as Defined by the Most Frequently Occurring Direction for Each Hour of the Day

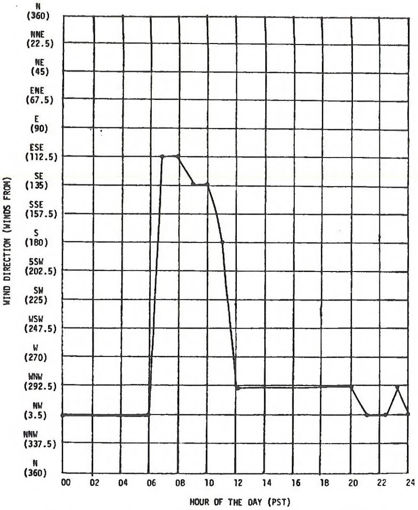


Figure 4.4-17

Diurnal Wind Direction Distribution at
Fresno, California (1960-1964)

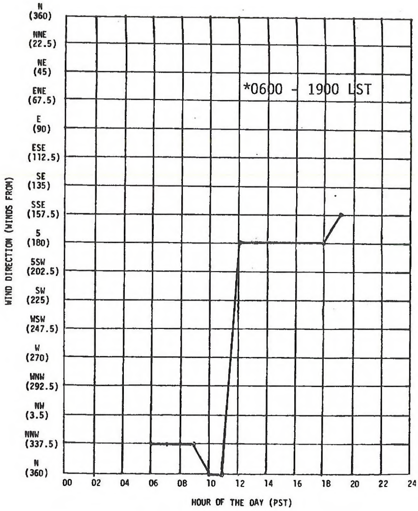


Figure 4.4-18

Diurnal Wind Direction Distribution at
Bishop, California (1960-1964)*

Note: Diurnal Wind Direction as Defined by the Most Frequently Occurring Direction for Each Hour of the Day

The effects of complex terrain in the Owens Valley region are evident in the diurnal wind direction analysis for Bishop. The analysis, based on data taken only during the daylight hours, shows that before noon, the flow is basically a northerly drainage flow from the higher altitude Long Valley into the Bishop region. In the afternoon, as the sun begins to heat the ground, a southerly flow is evident at Bishop as air begins to flow upslope into the Long Valley and along the eastward facing slopes of the Sierra, which determine the western boundary of the Owens Valley north of Bishop.

Wind Speed

Figures 4.4-19 through 4.4-22 provide the diurnal distribution of wind speed at Monterey, Stockton, Fresno and Bishop. The figures for each station are rather similar with maximum wind speeds occurring between 1600 and 1800 PST. The highest wind speeds occur at Stockton at just over 4 meters per second (mps) or 8.9 miles per hour (mph) where the sea breeze is relatively strong immediately downwind of the Carquinez Straits. Each station also shows the occurrence of lightest wind speeds during the early morning hours. Generally, just prior to sunrise, wind speeds are less than 2 mps (4.5 mph) at Monterey and between 2 and 3 mps (4.5 and 6.7 mph) at the other stations.

Wind speeds traditionally tend to be higher during the afternoon hours as surface heating results in good mixing through a deep layer in the atmosphere resulting in coupling between upper level stronger wind flow and conditions near the surface. At Monterey and Stockton, this tendency is also heightened, particularly during the summer months, by the sea breeze regime. A comparison of the graphs provided in the figures indicates that the diurnal wind speed distribution is most dissimilar at Fresno. Here, wind speeds tend to be higher during the daylight hours, however, nocturnal drainage flow is sufficiently strong to result in a very limited decrease in overall wind speeds during the night. As a result, the daily range of wind speed at this location is considerably less than that observed in other areas of the district.

4.4.3 Wind Speed Distribution

The distribution of wind speed as a function of the frequency of occurrence of designated wind speed categories is routinely available for first order stations within the Folsom District. Figures 4.4-23 through 4.4-27 provide seasonal and annual distributions of wind speed as a function of six distinct categories including; (1) 0-3 knots (0-3.5 mph), (2) 4-6 knots (4.6 - 6.9 mph), (3) 7-10 knots (8.1-11.5 mph), (4) 11-16 knots (12.7 - 18.4 mph), (5) 17-21 knots (19.6 - 24.2 mph) and (6) greater than 21 knots (24.2 mph). The frequency of calms is also provided in each figure as well as conversion factors to facilitate the use of both English and metric units.

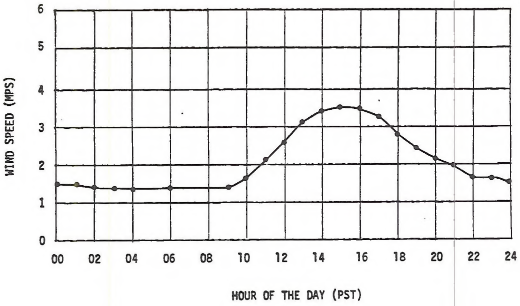


Figure 4.4-19
Diurnal Wind Speed Distribution at
Monterey, California (1958-1963)

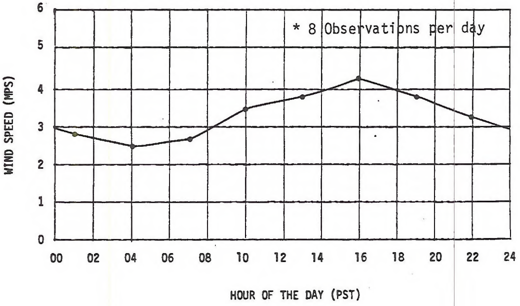


Figure 4.4-20
Diurnal Wind Speed Distribution at
Stockton, California (1972-1976)*

Note: Diurnal Wind Speed as Defined by Magnitude Average Speed
1 MPS = 2.237 MPH = 1.944 Knots

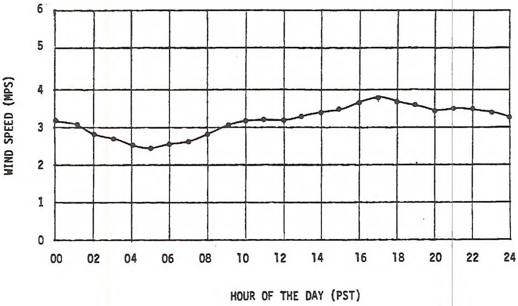


Figure 4.4-21
Diurnal Wind Speed Distribution at
Fresno, California (1960-1964)

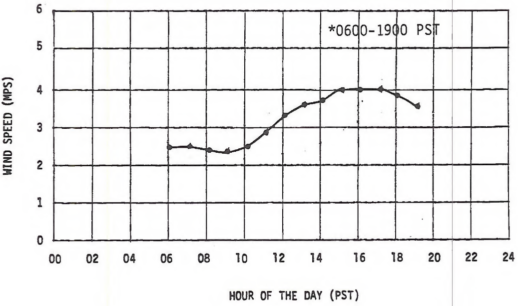


Figure 4.4-22
Diurnal Wind Speed Distribution at
Bishop, California (1960-1964)*

Note: Diurnal Wind Speed as Defined by Magnitude Average Speed
1 MPS = 2.237 MPH = 1.944 Knots

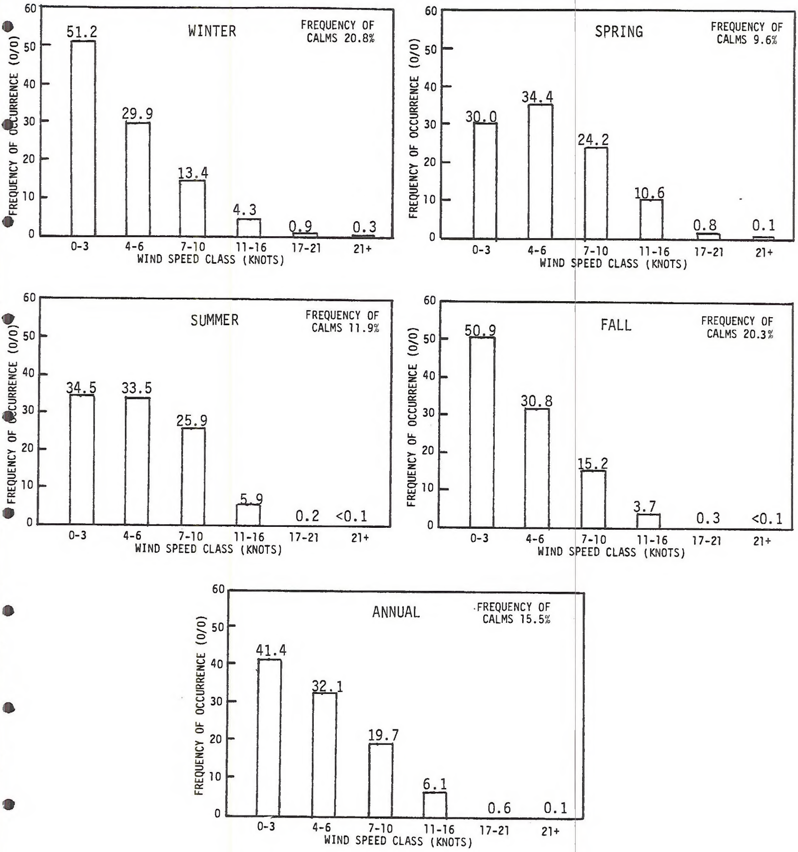


Figure 4.4-23

Frequency of Occurrence of Key Wind Speed Classes at Monterey, California (1958-1963)

Note: 1 MPS = 2.237 MPH = 1.944 Knots

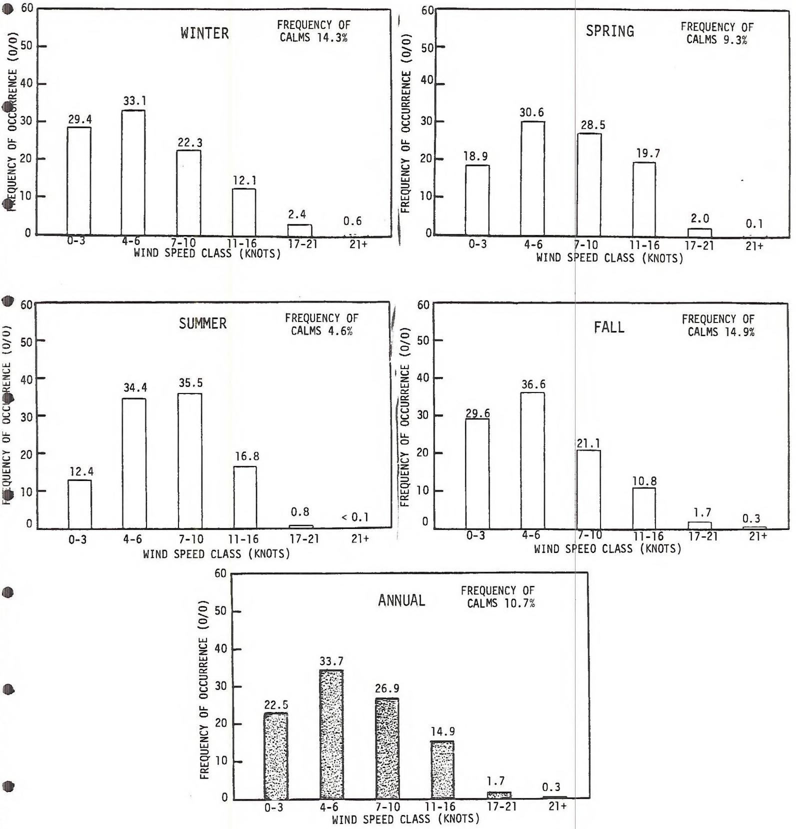


Figure 4.4-24

Annual-Seasonal
Frequency of Occurrence of Key Wind Speed Classes
at Sacramento, California (1966-1970)*

* 8 Observations Per Day

Note: 1 MPS = 2.237 MPH = 1.944 Knots

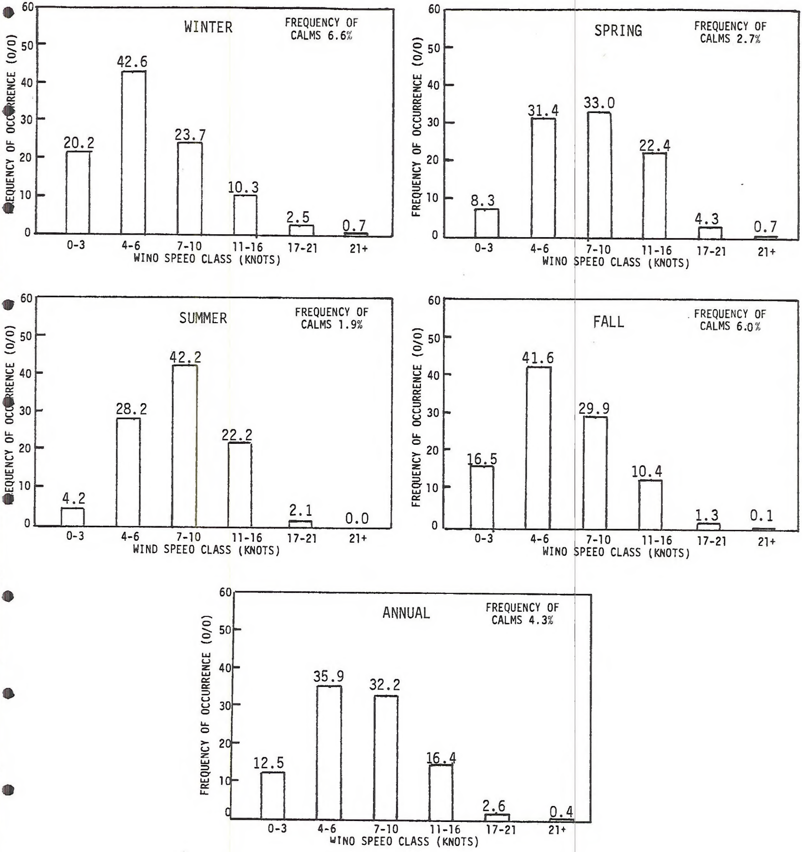


Figure 4.4-25

Frequency of Occurrence of Key Wind Speed Classes at Stockton, California (1972-1976)*

* 8 Observations per day

Note: 1 MPS = 2.237 MPH = 1.944 Knots

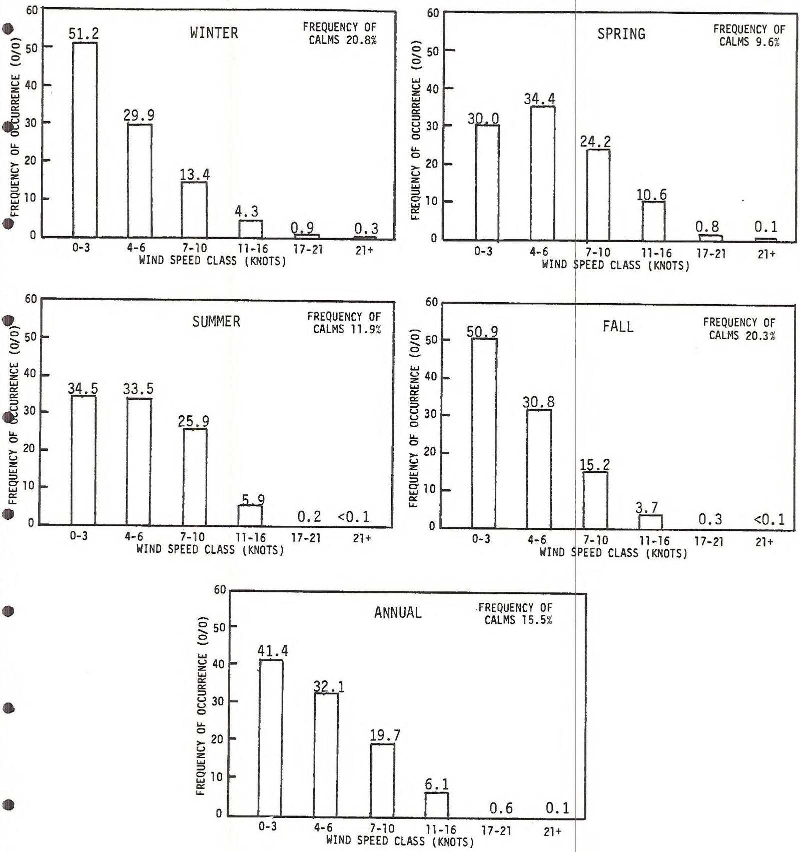


Figure 4.4-23

Frequency of Occurrence of Key Wind Speed Classes at Monterey, California (1958-1963)

Note: 1 MPS = 2.237 MPH = 1.944 Knots

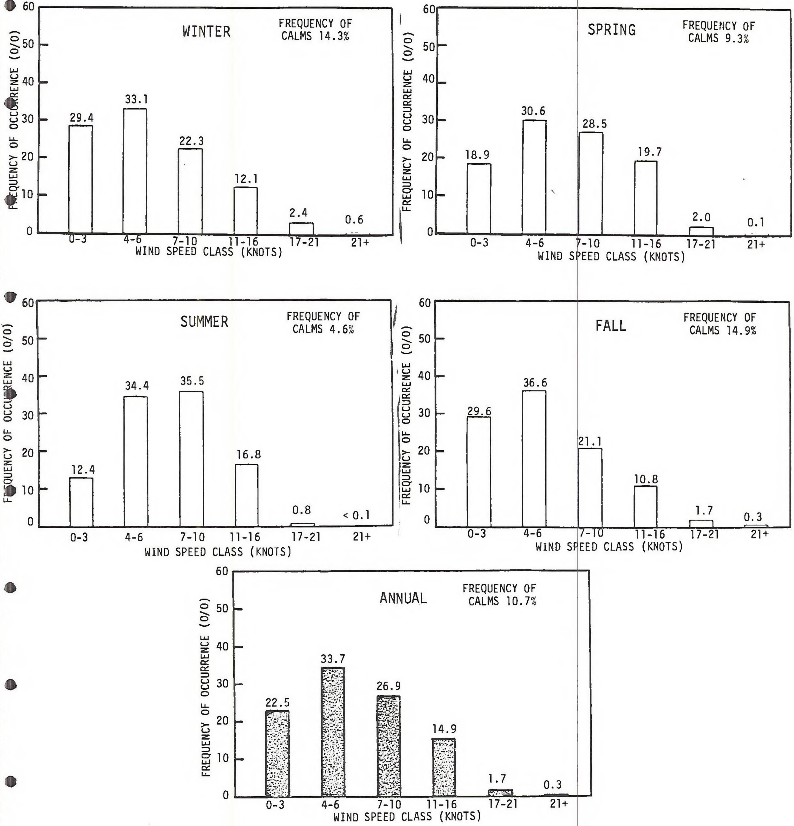


Figure 4.4-24

Annual-Seasonal
Frequency of Occurrence of Key Wind Speed Classes
at Sacramento, California (1966-1970)*

* 8 Observations Per Day

Note: 1 MPS = 2.237 MPH = 1.944 Knots

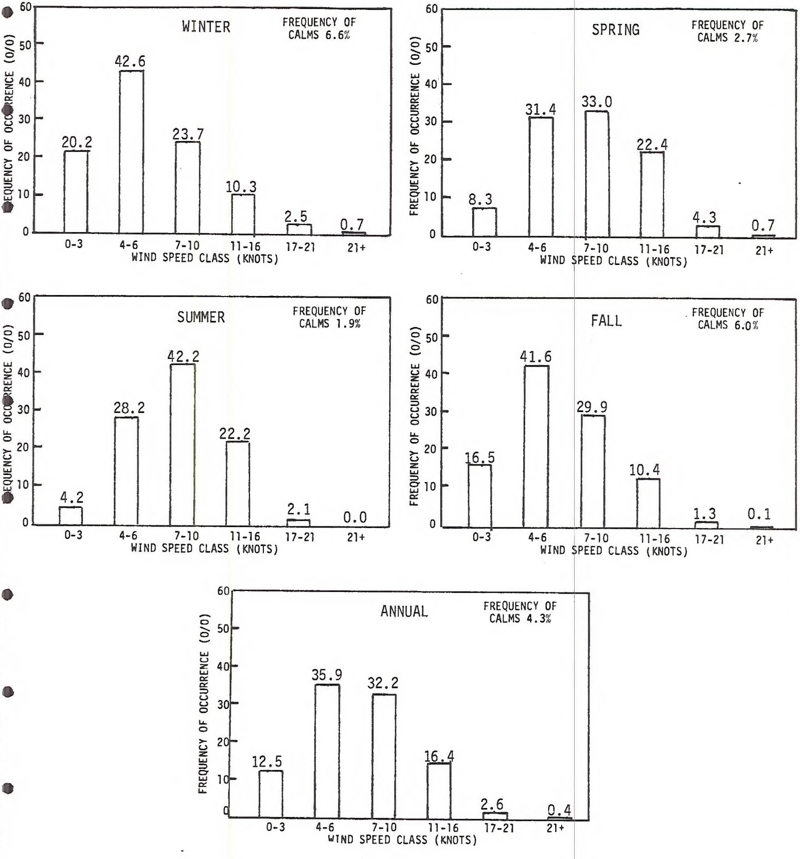


Figure 4.4-25

Frequency of Occurrence of Key Wind Speed Classes at Stockton, California (1972-1976)*

* 8 Observations per day

Note: 1 MPS = 2.237 MPH = 1.944 Knots

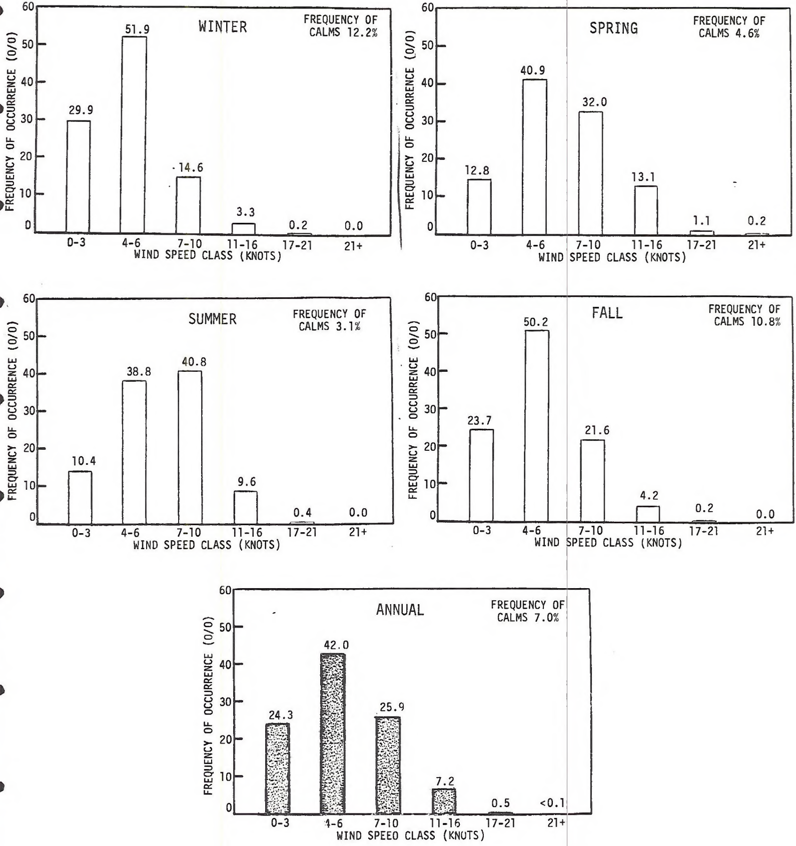


Figure 4.4-26

Annual-Seasonal
Frequency of Occurrence of Key Wind Speed Classes
at Fresno, California (1960-1964)

Note: 1 MPS = 2.237 MPH = 1.944 Knots

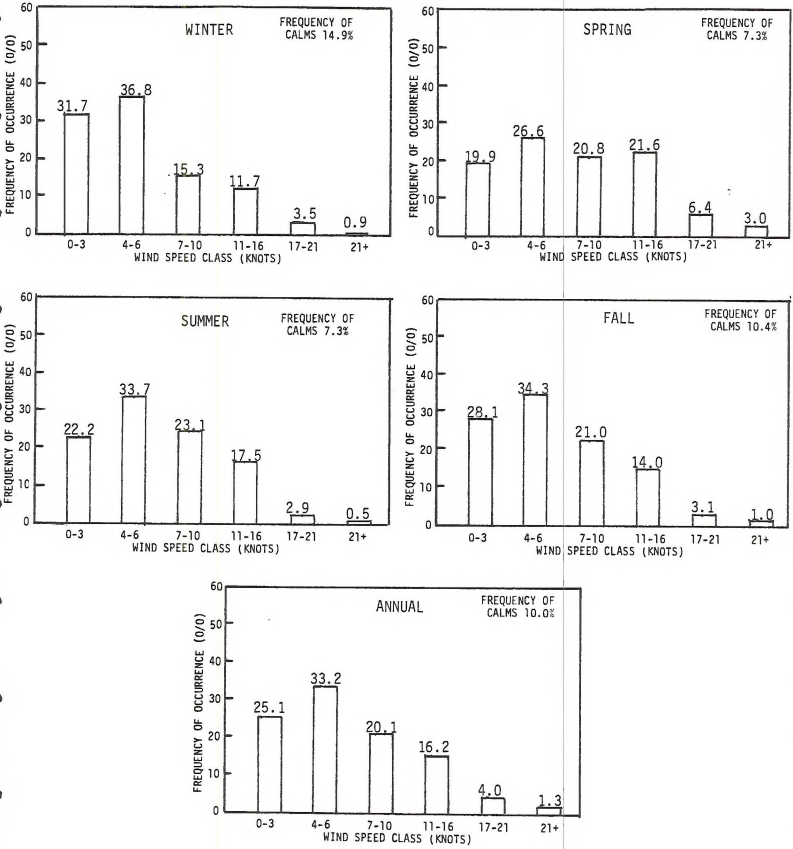


Figure 4.4-27

Frequency of Occurence of Key Wind Speed Classes at Bishop, California (1960-1964)*

*0600-1900 LST

The figures indicate that wind speeds tend to be strongest during the spring and summer and lightest during the fall and winter at all stations within the Folsom District. The effect of the sea breeze is to increase wind speeds and this effect is most apparent at coastal and inland valley locations. Areas in the High Sierra and further east experience less variability in the seasonal distribution of wind speed. However, wind speeds tend to be higher in these areas as surface heating and terrain effects dominate at well exposed locations. It should be noted that the distribution of wind speed at locations not well represented by the data presented in Figures 4.4-23 through 4.4-27 may be considerably different if local terrain effects dominate. Accordingly, the reader is cautioned in the extrapolation of the information contained in this section if a particular area of interest is not well represented by the available data.

Wind Speed as a Function of Wind Direction

The distribution of wind speed as a function of wind direction provides important information for dispersion meteorological studies. For example, when sensitive areas are situated near possible sources of pollutants, it is often beneficial to examine the mean wind speed as to the flow from the direction of the source. Very low wind speeds are generally associated with stable or limited dispersion conditions and could serve to maximize pollutant impact in the sensitive area. High average wind speeds generally imply well-mixed conditions and would reduce downwind pollutant concentrations. Plots of annual average wind speed as a function of wind direction have been generated for Monterey, Sacramento, Stockton, Fresno and Bishop and are presented in Figures 4.4-28 through 4.4-32. In addition, the average annual wind speed independent of wind direction for each station is presented with each plot.

The data for Sacramento, Stockton and Fresno provide insight into the flow of air into the Sacramento and San Joaquin Valleys from the Pacific Ocean. In the previous section, the location of Stockton, at a point of divergence for air flowing eastward through the Carquinez Straits and then north to Sacramento or south to Fresno was discussed. The data for these stations, presented in Figures 4.4-29 through 4.4-31, are consistent with this analysis.

The plots of average annual wind speed as a function of wind direction are consistent with the discussion of winds in the Folsom district as presented in Sections 4.4.1 and 4.4.2. Air flows into the Central Valley through the Carquinez Straits to Stockton with the flow then diverging north towards Sacramento and south towards Fresno. Coastal locations in the Folsom District are represented by the data from Monterey which show that the strongest winds can be expected with flow from a northwesterly direction. Finally, the data for Bishop, once again, show the effects of complex terrain on the local wind field. Other

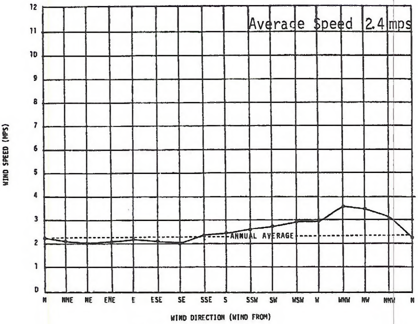


Figure 4.4-28

Annual Wind Speed as a Function of Wind Direction at Monterey, California (1958-1963)

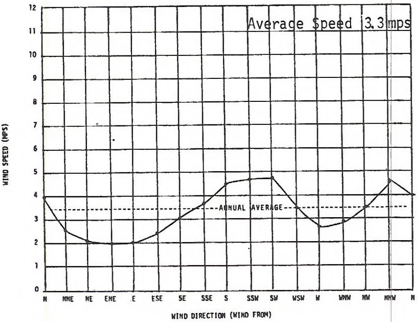


Figure 4.4-29

Annual Wind Speed as a Function of Wind Direction at Sacramento, California (1966-1970)*

* 8 Observations Per Day

Note: 1 MPS = 2.237 MPH = 1.944 Knots

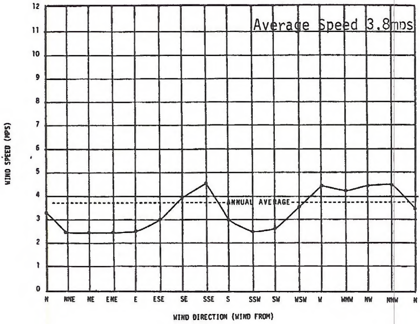


Figure 4.4-30

Annual Wind Speed as a Function of Wind Direction at Stockton, California (1972-1976)*

* 8 Observations Per Day

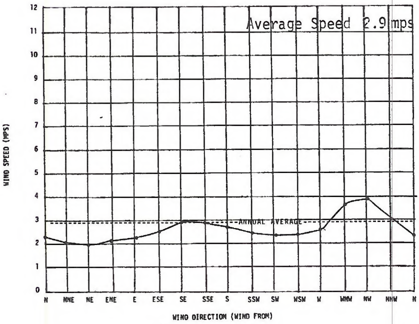


Figure 4.4-31

Annual Wind Speed as a Function of Wind Direction at Fresno, California (1960-1964)

Note: 1 MPS = 2.237 MPH = 1.944 Knots

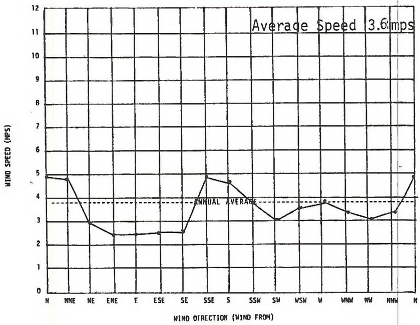


Figure 4.4-32
Annual Wind Speed as a Function of Wind Direction
at Bishop, California (1960-1964)*

* 0600 - 1900 LST

Note: 1 MPS = 2.237 MPH = 1.944 Knots

mountainous locations within the Folsom District will not experience the largely north-south flow experienced at Bishop as the wind flow will largely depend on local topographical features.

4.4.4 Persistence Analyses

The persistence of both wind speed and wind direction also plays a very functional role in a complete analysis of dispersion meteorology. For example, the persistence of a particular wind direction provides information relative to the likelihood of continued impact at a given receptor location for either existing or proposed sources. In terms of wind speed, low wind speeds can often provide a maximum impact in a given region particularly if they persist for any length of time. Therefore, the persistence of calms or lower wind speed classes can also provide very useful information relative to the overall dispersion potential.

Tables 4.4-1 through 4.4-3 provide wind direction and wind speed persistence tables for Monterey, Fresno, and Bishop, California. These data provide information on the persistence of these parameters at a coastal, inland valley and mountainous station. The data are provided in terms of key persistence intervals of 2, 4, 10 or 24 or more hours.

4.4.5 Trajectory Analyses

Trajectory analyses are used in dispersion meteorology to describe regional transport. Trajectory analyses are developed through the identification of prevailing flow at key stations to establish the mean flow over a large geographical area. These data are then useful in determining the probable large scale transport of pollutants.

In the Folsom District, Figures 4.4-33 through 4.4-36 provide the direction of prevailing flow at key stations in the Folsom District at 0800, 1400, 2000 and 0200 PST. These data are presented for Monterey, Stockton, Coalinga, Fresno and Bishop. With the exception of Coalinga, the analysis was developed utilizing available STAR data for these first order stations. The Coalinga data represents analysis prepared by private industry subsequent to a monitoring program at a proposed oil field secondary recovery operation.

It is not felt that the available data on prevailing flow at these stations is sufficient to definitively determine the actual trajectory of air parcels throughout this large area. Accordingly, the prevailing wind direction is only plotted at each of the stations for which data are available. However, some useful conclusions can be drawn from the analysis.

Figure 4.4-33 provides the prevailing flow at the indicated locations at 0800 PST. At this time of the morning, drainage flow conditions dominate at most sites, as evidenced by

Table 4.4-1

Wind Direction Persistence

at Monterey, California

(1959 - 1963)

Persistence Interval	Frequency (%) for Winds From															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
2 or More Hours	2.5	0.4	0.4	0.3	3.6	3.8	2.3	0.9	1.6	2.5	4.0	6.6	6.6	6.9	7.6	5.1
4 or More Hours	0.9	0.1	0.1	0.1	1.2	1.3	0.7	0.2	0.6	0.8	1.1	2.5	2.5	2.9	3.4	1.9
10 or More Hours	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1
24 or More Hours	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Wind Speed Persistence

at Monterey, California

(1959 - 1963)

Persistence Interval	Frequency (%) of Wind Speeds for the Following Classes (knots)						
	Calm	1-3	4-6	7-10	11-16	17-21	21+
2 or More Hours	14.0	27.2	24.4	7.7	1.7	0.2	0.0
4 or More Hours	7.0	13.9	13.1	3.4	0.8	0.1	0.0
10 or More Hours	0.9	1.4	1.7	0.1	0.1	0.0	0.0
24 or More Hours	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.4-2

Wind Direction Persistence

at Fresno, California

(1960 - 1964)

Persistence Interval	Frequency (%) for Winds From															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
2 or More Hours	0.8	0.2	0.6	1.0	2.1	4.7	3.5	1.6	1.4	0.6	0.4	0.6	1.9	15.1	15.8	2.7
4 or More Hours	0.1	0.0	0.1	0.1	0.4	1.9	1.1	0.2	0.3	0.1	0.0	0.1	0.2	9.0	9.2	0.6
10 or More Hours	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.6	2.4	0.1
24 or More Hours	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0

Wind Speed Persistence

at Fresno, California

(1960 - 1964)

Persistence Interval	Frequency (%) of Wind Speeds for the Following Classes (knots)						
	Calm	1-3	4-6	7-10	11-16	17-21	21+
2 or More Hours	4.0	10.6	34.5	20.9	5.5	0.3	0.1
4 or More Hours	1.2	3.7	19.7	12.5	3.2	0.1	0.1
10 or More Hours	0.1	0.1	2.2	1.8	0.6	0.0	0.0
24 or More Hours	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.4-3

Wind Direction Persistence*

at Bishop, California

(1960 - 1964)

Persistence Interval	Frequency (%) for Winds From															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
2 or More Hours	8.8	2.9	0.2	0.1	0.1	0.1	0.2	6.3	8.5	2.2	1.2	1.2	1.4	1.2	4.7	6.0
4 or More Hours	3.4	0.9	0.0	0.0	0.0	0.1	0.1	2.3	3.4	0.2	0.1	0.1	0.2	0.1	1.1	1.1
10 or More Hours	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24 or More Hours	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Wind Speed Persistence*

at Bishop, California

(1960 - 1964)

Persistence Interval	Frequency (%) of Wind Speeds for the Following Classes (knots)						
	Calm	1-3	4-6	7-10	11-16	17-21	21+
2 or More Hours	5.5	19.3	19.0	11.0	10.6	1.3	0.2
4 or More Hours	1.5	7.7	6.3	4.1	6.2	0.4	0.1
10 or More Hours	0.0	0.2	0.1	0.1	0.7	0.0	0.0
24 or More Hours	-	-	-	-	-	-	-

*Observations taken between 0600-1900 PST, limiting maximum persistence time to 14 hours.

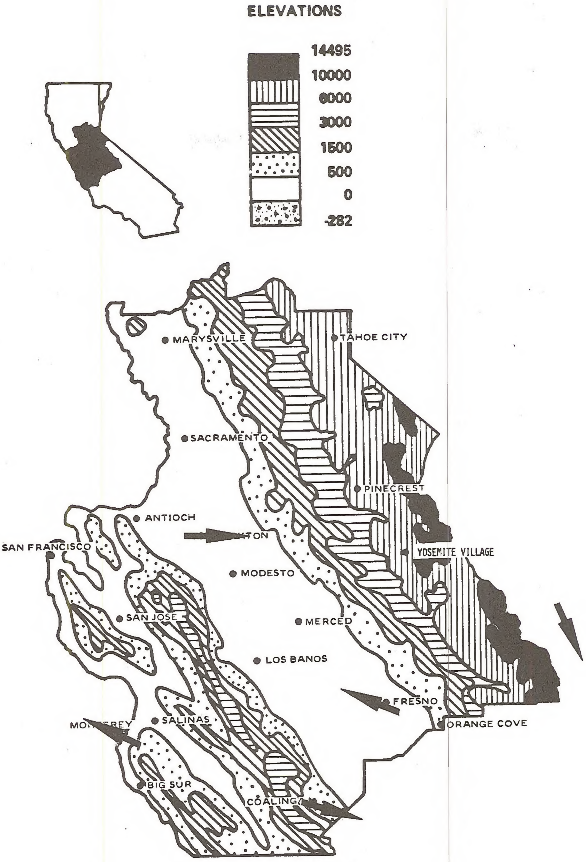


Figure 4.4-33
Annual Prevailing Flow in the Folsom District
at 0800 PST

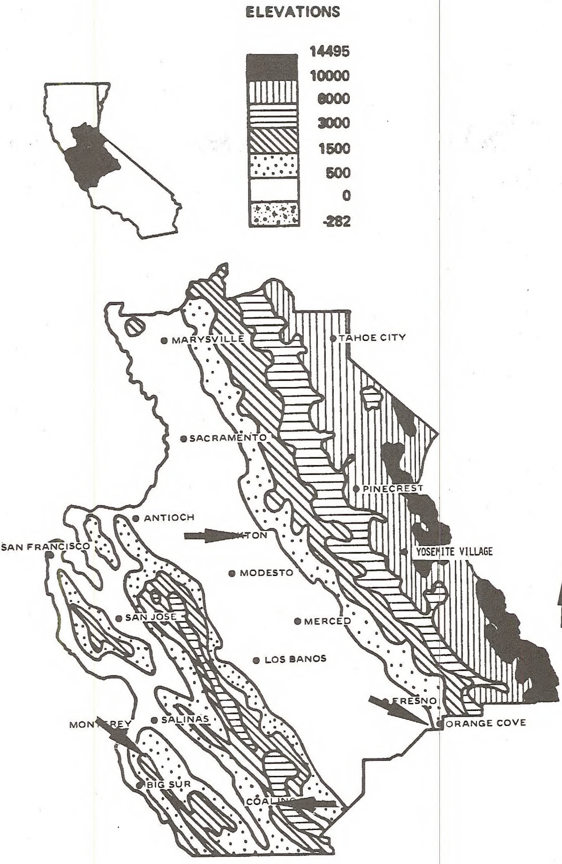


Figure 4.4-34
Annual Prevailing Flow in the Folsom District
at 1400 PST

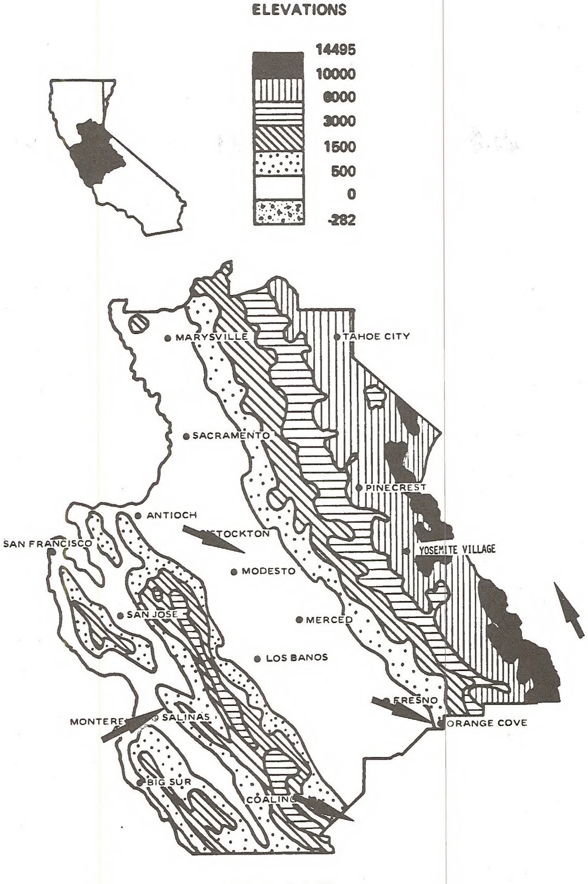


Figure 4.4-35
Annual Prevailing Flow in the Folsom District
at 2000 PST

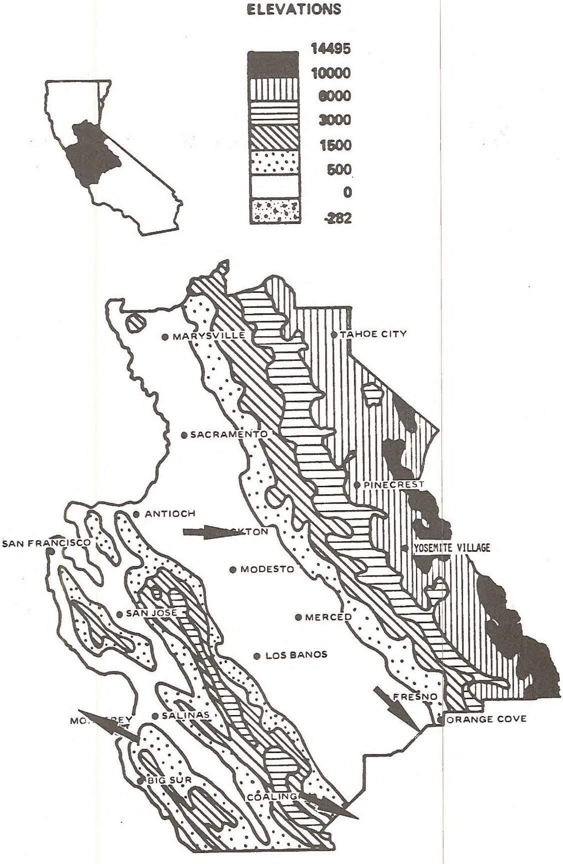


Figure 4.4-36
Annual Prevailing Flow in the Folsom District
at 0200 PST

flow away from areas of elevated terrain at each station. At Bishop, for example, downvalley flow is evident from the Long and Owens Valley, while at Fresno and Coalinga, drainage winds from nearby areas of elevated terrain are apparent.

By 1400 PST or roughly mid-afternoon, Figure 4.4-34 indicates that prevailing flow has become established at most locations.. This includes the impact of the sea breeze at Monterey, Stockton, and even at Fresno. Coalinga and Bishop show winds indicative of upslope flow conditions which result from mid-afternoon surface heating effects.

Figure 4.4-35 indicates that by 2000 PST conditions are largely unchanged from that observed during the mid-afternoon with the exception that the prevailing onshore northwesterly flow at Monterey has been replaced by light west-southwesterly flow. This represents a transitional period at that location prior to the onset of drainage winds. Drainage winds are already becoming established at Coalinga, as indicated by flow from the west-northwest and at Bishop, the drainage flow regime has not yet replaced normal daytime flow conditions. Finally, at 0200 PST, drainage flow conditions are evident at all staions with the exception of Fresno where flow is still from the prevailing northwesterly direction.

In summary, the data provided in Figures 4.4-33 through 4.4-36 indicate the dominance of prevailing flow during the daylight hours and drainage flow during the early morning hours as indicated in earlier sections. Prevailing flow is typically dictated by the sea breeze regime at most coastal and valley locations. At other locations close to areas of substantial terrain, such as Coalinga and Bishop, terrain effects such as upslope, surface-heating induced flow, become dominant. At night, drainage flow conditions are apparent at most locations in the Folsom District.

Data have also been prepared by (Meteorological Research, Inc.) MRI on mean low level winds in the Central Valley of California during the smog season of August through December. Data for September have been extracted for this study and are presented in Figures 4.4-37 through 4.4-42 for 0600, 0900, 1200, 1500, 1800, and 2400 PST. These figures provide mean surface flow in conjunction with low level inversions which typically produce the highest pollutant potential.

These figures, provided for the month of September, indicate that during limited dispersion conditions, flow from the industrialized Bay Area generally is transported into the remainder of the Folsom District. This movement continues into the Sierra Nevada during the mid-afternoon period and would indicate that BLM lands located in higher terrain on the westward facing slopes of the Sierra are along the downwind trajectory of polluted air masses from the San Francisco Bay Area and Central Valley locations.

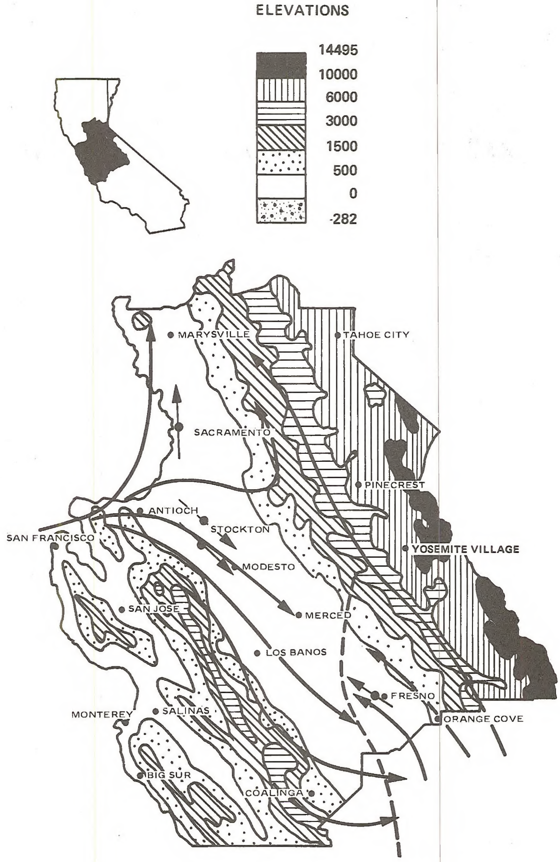


Figure 4.4-37
Low Level Inversion Mean Wind Flow in the San Joaquin Valley for September at 0600 PST

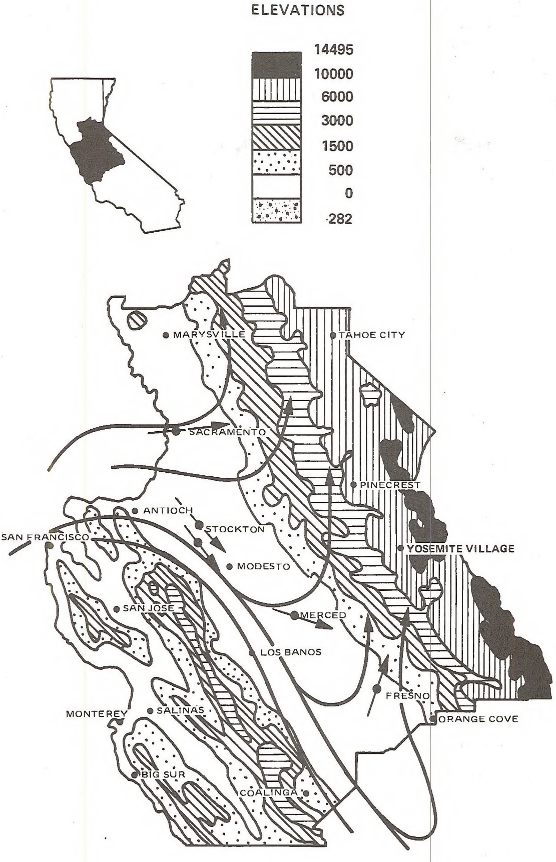


Figure 4.4-38
Low Level Inversion Mean Wind Flow in the
San Joaquin Valley for September at 0900 PST

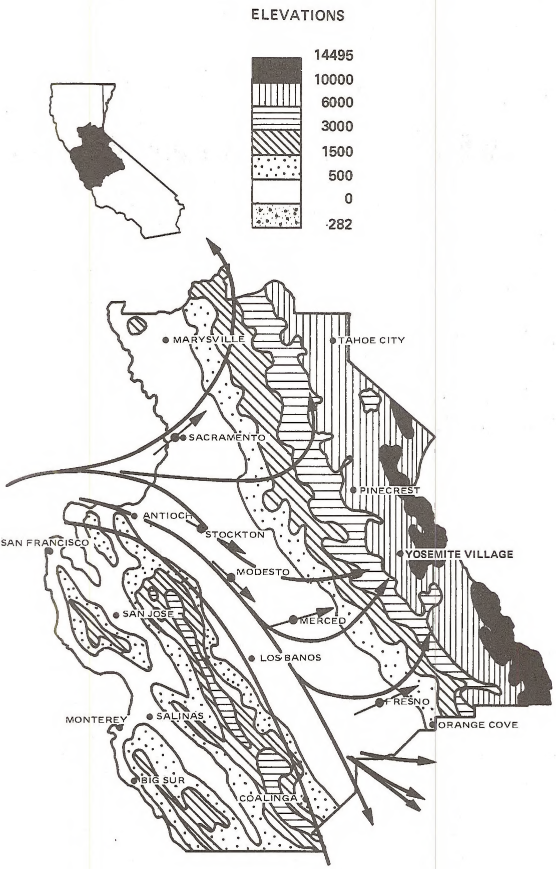


Figure 4.4-39
Low Level Inversion Mean Wind Flow in the
San Joaquin Valley for September at 1200 PST

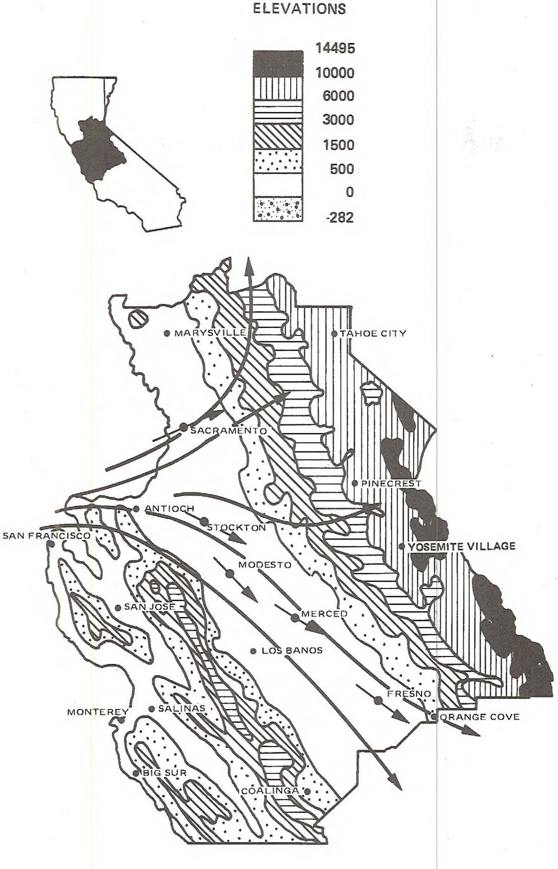


Figure 4.4-40
Low Level Inversion Mean Wind Flow in the San Joaquin Valley for September at 1500 PST

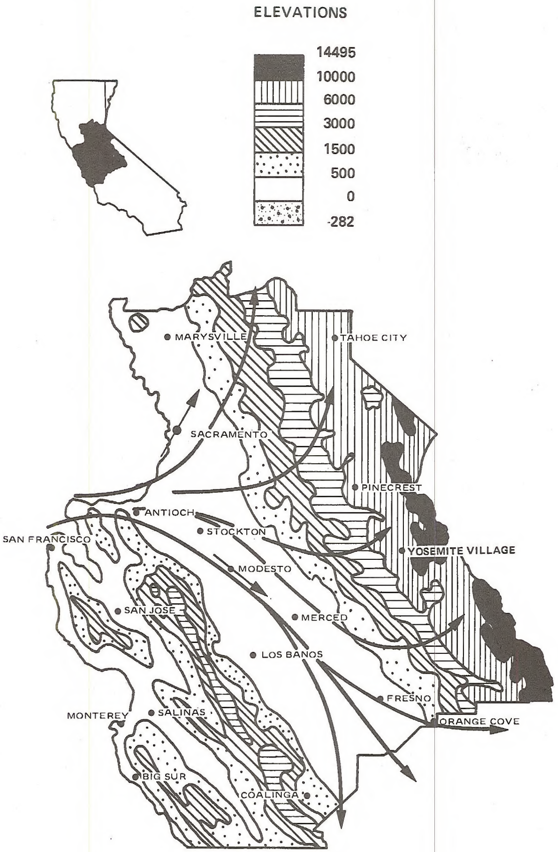


Figure 4.4-41
Low Level Inversion Mean Wind Flow in the
San Joaquin Valley for September at 1800 PST

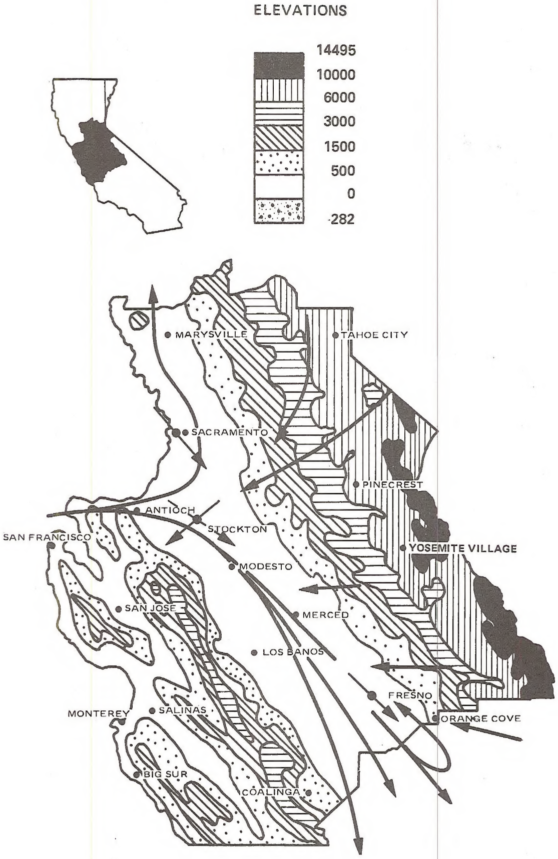


Figure 4.4-42
Low Level Inversion Mean Wind Flow in the San Joaquin Valley for September at 2400 PST

4.4.6 Winds Aloft

Upper level winds provide a measure of the mean transport above the surface boundary layer. However, upper air data are only available for a very few NWS station locations and, for this reason, most major pollutant studies require the collection of onsite data to provide a measure of winds aloft. In California, upper air data are only routinely collected by the NWS at Oakland, Santa Monica and San Diego.

Upper level wind data at such NWS stations are generally taken by radiosonde. This is a balloon, tracked by radar which transmits data on temperatures aloft as well as wind speed and wind direction through the tracking of the balloon's downwind position. Figure 4.4-43 provides a summary of seasonal upper air data taken at Oakland, from the surface to the top of the atmosphere. The data indicate that at Oakland, winds tend to be from the west through northwest during all seasons in the lower portion of the atmosphere. In air pollution studies, levels above 850 millibars (4500 feet) are generally not of interest, as most pollutant transport is within the lowest few thousand feet. Upper level winds over most of California show a characteristic flow from the northwest quadrant at most levels. The impact of the dominating terrain characteristics of much of California and the Folsom District is felt most critically in the first few thousand feet, the area of interest in pollution studies.

As stated previously, Oakland is the only regular upper air meteorological station operated by the NWS in the Folsom District. Other winds aloft data have been collected by the (California Air Resources Board) CARB as part of its ongoing analysis of pollutant transport conditions in the Central Valley as well as for use in the development of burn/no-burn forecasts. This data collection program by the CARB is primarily geared to the identification of local inversion meteorology and the establishment of the mean height of the mixing layer. Data available from pilot balloon releases by the CARB as well as through programs operated by private industry indicate a continuation of the flow observed at the surface gradually turning towards the west through northwest as commonly observed over California at upper levels.

Holzworth (1972) has provided seasonal and annual values of the mean wind speed averaged through the mixing layer for both the morning and afternoon hours. These data are particularly useful in dispersion studies as they provide a realistic measure of mean transport in the layer of the atmosphere in which most pollutants are mixed.

Table 4.4-4 provides a summary of these data for the Folsom District. The data provide a range of values across the district which indicate that lower wind speeds occur during the morning hours as opposed to the afternoon. In addition, winter

Figure 4.4-43

Seasonal

Vertical Wind Profile

For Oakland, California

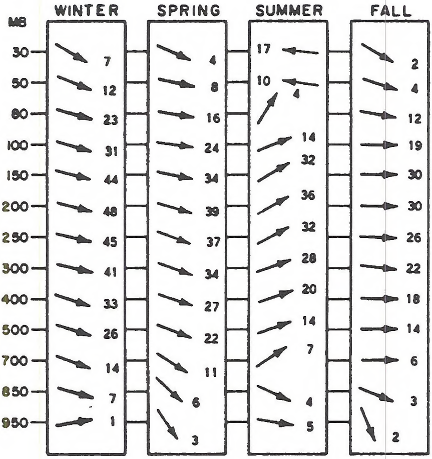


Table 4.4-4

Seasonal and Annual Average Wind Speeds (MPS) in the Mean Mixing Layer Over the Folsom District

	Morning	Afternoon
Winter	<2 - 4	3 - 4
Spring	3 - 4	5 - 6
Summer	<2 - 3	5 - 6
Fall	<2 - 3	4 - 5
Annual	2 - 3	4 - 5

1 mps = 0.447 mph

and fall tend to be the most restrictive seasons in terms of lower wind speeds. A review of the graphical distribution of these data as provided by Holzworth indicates that the lower values occur over the Central Valley regions with higher wind speeds generally over the Sierra and the Coastal Zone. It is pointed out, however, that the Holzworth data are based upon an analysis of data available from Oakland, Santa Monica and San Diego and as such are based upon very few data points. For this reason, the reader is cautioned in the utilization of these data, particularly in areas with important terrain effects.

One of the more intriguing aspects of the upper air meteorology of the Central Valley is the apparent existence of a low level jet during the nighttime hours during summer. The existence of fairly strong upvalley flow has been noted at a height of between 640 and 1290 feet above the ground during the nighttime hours. Wind speeds of 15 to 20 meters per second (33 to 44 miles per hour), are apparently not uncommon. It has been theorized that this low level jet is a function of large scale thermal pressure patterns. The jet is most poorly developed in instances where the stable marine layer is deepest, which allows air to flow into the Central Valley over many of the passes in the Coast Range, thereby destroying the tendency for concentrated upvalley flow across the Central Valley floor. This low level jet would have a tendency to rapidly move pollutants in the lower atmosphere during the nighttime hours, possibly even out of the Central Valley and over the Tehachapi Mountains to the southeast.

4.5 ATMOSPHERIC STABILITY

The definition of atmospheric stability throughout the Folsom District is a critical component of the dispersion meteorological analysis. Section 4.2.2 provides a detailed discussion of atmospheric stability and its role in defining the dispersion of airborne effluents. Figure 4.5-1, which also appears in Section 4.2.2, summarizes the dispersion characteristics associated with the various stability categories for the traditional dispersion scenarios. This section provides analyses that are designed to identify specific characteristics of atmospheric stability. These analyses include:

- Seasonal and Annual Distributions
- Diurnal Distributions
- Persistence Analyses
- Stability Wind Roses

These analyses describe a key component of the dispersion characteristics of the Folsom District. Data are unfortunately available for only a few key stations in the region and the reader is cautioned in the use of these analyses, particularly in areas of rugged terrain or other locations not well represented by the available data.

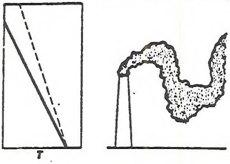
4.5.1 Seasonal and Annual Stability Distributions

Annual stability distributions provide a means of quantifying the atmospheric dispersive power of an area in an easily comparative form. The seasonal variations in stability reflect the extent to which the dispersive power of the atmosphere changes with the seasons.

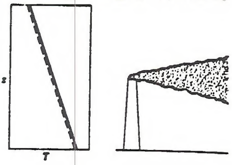
The ability of the local atmosphere to disperse airborne effluents from specific source types can be discussed in terms of atmospheric stability. When the atmosphere is stably stratified, the impact of ground level, non-buoyant emissions, will be greatest as both vertical and lateral diffusion are restricted. Examples of such emissions include automobile exhaust and fugitive dust. Typical similar sources which might impact BLM lands include range management activities and the use of unpaved surface roads. The lower atmosphere is most likely to be stable on calm clear nights when cold air tends to collect at lower elevations. Emissions from tall stacks under such conditions will have little or no impact at ground level as the plume remains relatively intact aloft. Fall and winter are the seasons when such conditions occur most frequently in California and in most areas of the United States. The impact of ground level sources is therefore at a maximum during these seasons.

Intense surface heating results in considerable convective activity and unstable conditions. Under such conditions, vertical diffusion is considerable and "fumigation" can occur as

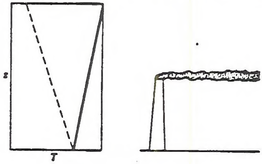
Stability Category A-C; Looping



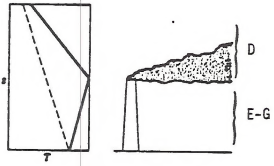
Stability Category D; Coning



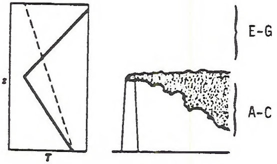
Stability Category E-G; Fanning



Stability Categories As Noted; Lofting



Stability Categories As Noted; Fumigation



Stability Categories As Noted; Trapping Inversion

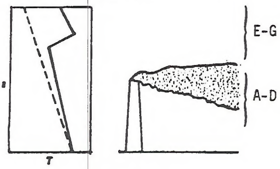


Figure 4.5-1

Typical Plume Behavior*

* Plume behavior influenced by the temperature lapse rate above and below the release height. The dashed lines in the profiles are the adiabatic lapse rates, included for reference, while the solid lines indicate the actual lapse rate. The Pasquill stability categories are also provided.

emissions from elevated sources are brought rapidly to the surface creating maximum ground-level concentrations. Examples of large elevated pollutant sources which could potentially impact BLM lands include power plants and other large industrial sources as well as large forest fires.

Finally, neutral atmospheric stability, characterized by a windy, well-mixed atmosphere, and generally indicative of good atmospheric dispersion, can result in locally high ground-level concentrations for stacks of intermediate height or stacks whose height is not substantially greater than the height of surrounding buildings. Most moderate sized industrial complexes are indicative of this source type; refineries and other processing industries serve as typical examples. In such cases, strong winds can bring the plume rapidly to the surface, resulting in high gound-level pollutant concentrations in a condition known as "downwash". Neutral conditions may also result in the reentrainment of loose dust and soil particles associated with deserts and overgrazed arid lands. Reduced visibility and increased atmospheric particulate loading may occur in nearby populated areas as a result.

The following discussion provide seasonal and annual distributions of atmospheric stability which, combined with a knowledge of source types, can be used to identify probable periods of maximum impact. Seasonal and annual stability frequency distributions for various site locations throughout the Folsom District are provided in Figures 4.5-2 through 4.5-6. These data show that there is a significant difference in the atmospheric stability frequency distributions between the coastal area, the Central Valley, and the mountainous regions.

The Central Valley experiences a greater frequency of cloud cover during the fall and winter months, whereas the coastal area experiences its greatest cloud cover during the spring and summer months. This is evident in the high frequency of neutral conditions (50%) at Monterey during the summer, and the high frequency of neutral conditions at Fresno and Stockton during the winter months. On an annual basis, the difference between coastal and valley locations is less apparent, with a slightly higher frequency of stable cases occurring in the Central Valley. The higher frequency of neutral conditions at Stockton, when compared with Fresno during the summer season reflects the marine influx from the San Francisco Bay area and shows the modification of that marine air as it flows southeast down the San Joaquin Valley and north into the Sacramento Valley.

In the mountainous regions, the winter season experiences the highest frequency of stable conditions. This reflects the shorter days and reduced solar insolation during the winter.

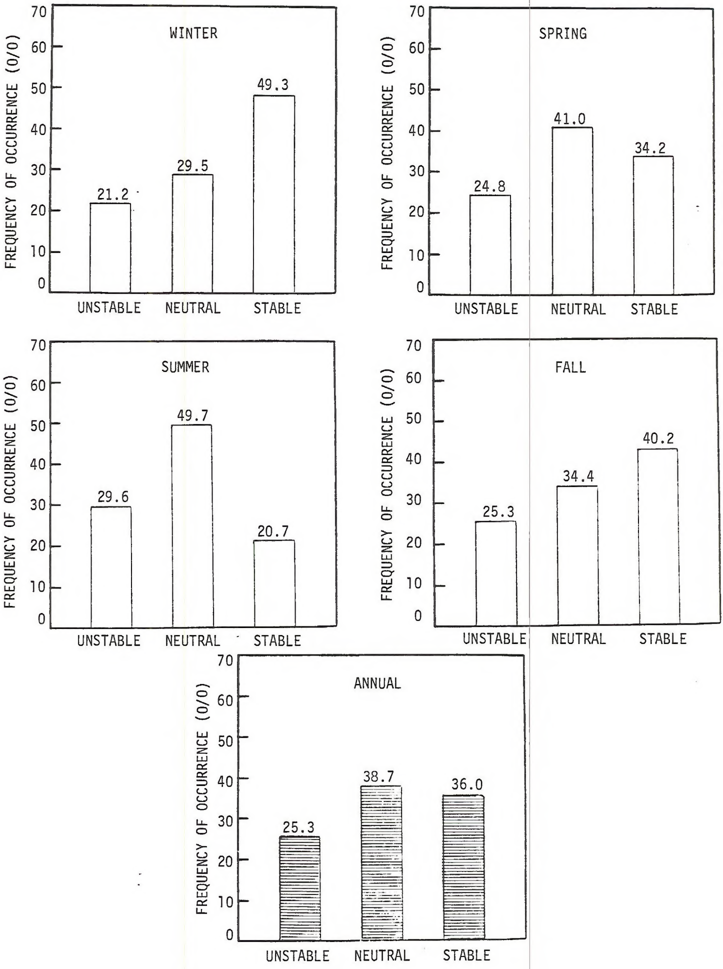


Figure 4.5-2

Seasonal/Annual Distribution of Atmospheric Stability
Monterey, California

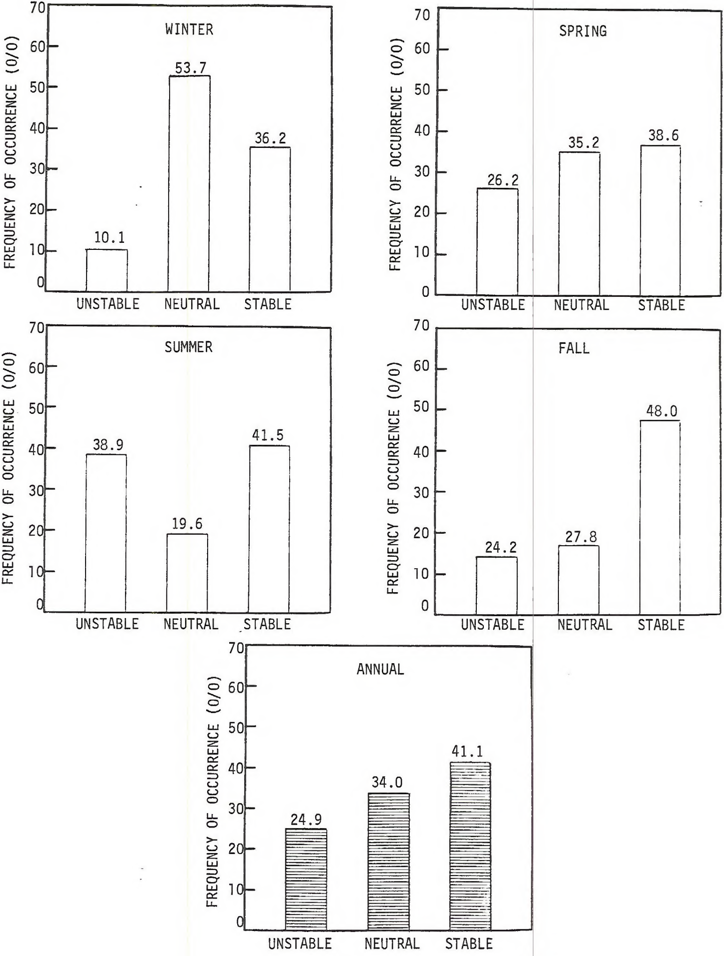


Figure 4.5-3

Seasonal/Annual Distribution of Atmospheric Stability
Sacramento, California

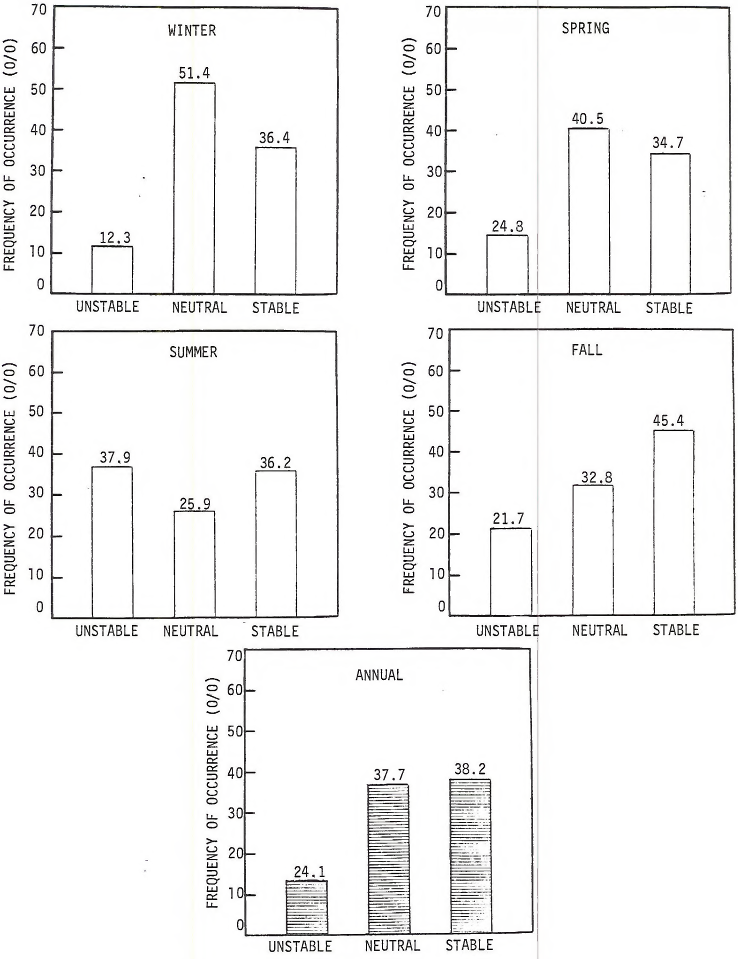


Figure 4.5-4

Seasonal/Annual Distribution of Atmospheric Stability
Stockton, California

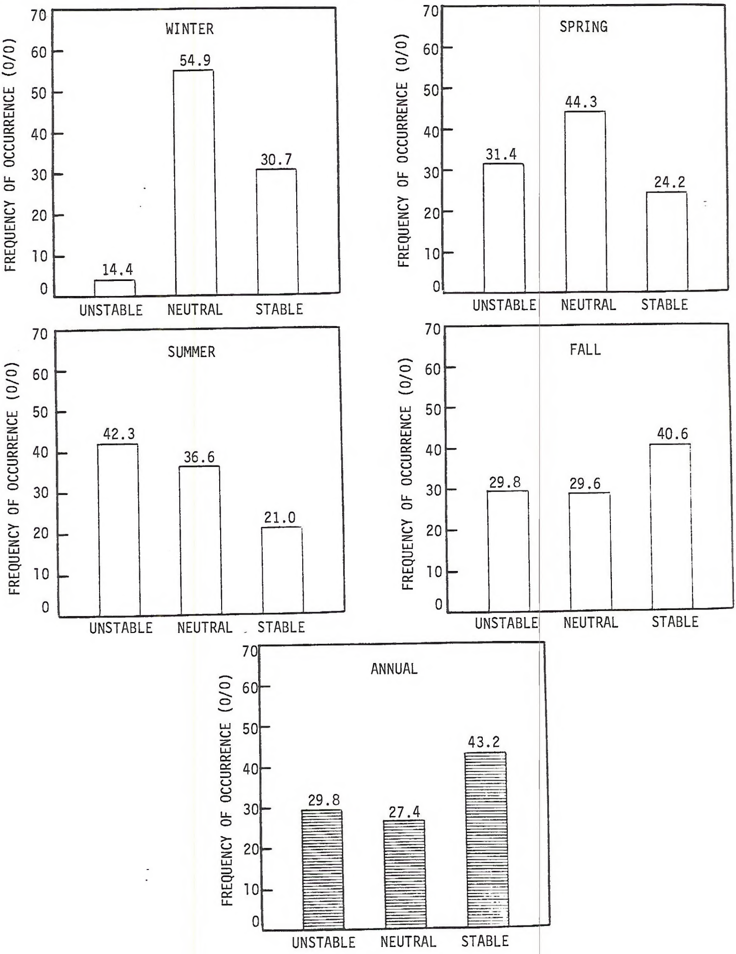


Figure 4.5-5

Seasonal/Annual Distribution of Atmospheric Stability
Fresno, California

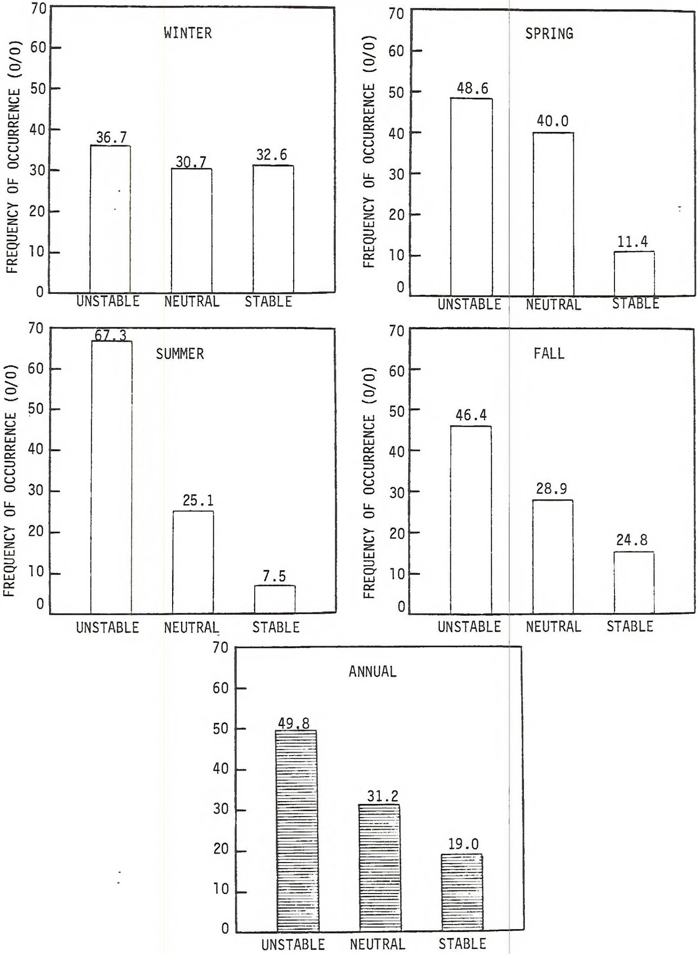


Figure 4.5-6

Seasonal/Annual Distribution of Atmospheric Stability
Bishop, California

4.5.2 Diurnal Stability Distributions

The diurnal distribution of stability provides a means of determining the probability that any one category will occur at any given hour of the day. This information, together with the seasonal and annual stability distributions, provides a complete picture of the stability characteristics at any given station. Since most human and industrial activity is generally concentrated during the daylight hours, the diurnal stability distributions allow for intensified study of the dispersion conditions prevalent during those and other pertinent periods.

The diurnal stability distributions for the four stations for which digitized data were available are presented in Table 4.5-1 and Figure 4.5-7. These data were averaged over the respective periods of record for each station, and as such are representative of an annually averaged day; seasonal variations are not expected to be significant on a diurnal basis.

As can be seen from the table, all four stations exhibit very sharp increases in stable conditions after about 1600 PST and very sharp decreases before 1000 PST. These times correspond with the average limits of sunset and sunrise, respectively, on an annual basis. The maximum frequency of stable conditions occurs between 0200 and 0400 PST.

The onset of unstable conditions closely matches the rapid decay of stable conditions near sunrise. Conversely, unstable conditions decay rapidly at the onset of stable conditions near sunset. The overlaps evident in the stable and unstable categories in Table 4.5-1 are a result of the annual variations in the onsets of sunrise and sunset; seasonal plots of the diurnal stability distributions would serve to reduce these overlaps. The maximum frequency of unstable conditions occurs between 1100 and 1300 PST. Again, as would be expected from the definition, unstable conditions do not occur at any station after radiational sunset and before radiational sunrise.

Neutral conditions are shown to occur at all four stations at all hours of the day, showing a tendency to occur more frequently during the afternoon hours when wind speeds are generally higher. Some diurnal stability trends can be inferred from the data presented for these four stations. As one moves from the coastal region inland, the frequency of stable conditions at night and the frequency of unstable conditions during the day increases. This generally reflects the decreased availability of atmospheric water vapor (clouds, fog, etc.) with distance from the Pacific Ocean.

4.5.3 Stability Persistence

Stability persistence tables give an indication of the tendency of a stability category to persist for extended periods of time. This information can be used to identify the frequency

Table 4.5-1

Diurnal Frequency Distribution of Stability

in the Folsom District

Hour	Fresno			Stockton			Monterey			Bishop		
	U	N	S	U	N	S	U	N	S	U	N	S
1	0	22.6	77.5	-	-	-	0	39.7	60.3	-	-	-
2	0	21.1	78.9	-	-	-	0	42.4	57.5	-	-	-
3	0	20.8	79.2	0	26.4	73.6	0	42.8	57.2	-	-	-
4	0	28.0	80.0	-	-	-	0	43.9	56.1	-	-	-
5	0	21.3	78.7	-	-	-	0	45.5	54.5	-	-	-
6	5.9	36.9	57.2	31.5	41.2	27.2	3.5	45.9	50.6	11.1	25.9	63.1
7	40.9	32.1	27.0	-	-	-	18.3	46.9	34.7	42.6	23.3	34.0
8	60.0	33.3	6.6	-	-	-	37.9	48.0	14.1	63.2	26.8	10.2
9	71.1	28.8	0	62.6	37.4	0	58.4	41.5	0	81.2	18.8	0
10	72.6	27.4	0	-	-	-	62.9	37.2	0	82.3	17.8	0
11	75.4	24.6	0	-	-	-	72.2	27.8	0	83.2	16.8	0
12	77.6	22.4	0	68.5	31.5	0	76.0	24.1	0	81.9	18.1	0
13	78.1	21.9	0	-	-	-	75.0	25.0	0	77.9	22.1	0
14	75.6	24.4	0	-	-	-	68.2	31.8	0	66.1	33.9	0
15	71.9	28.1	0	30.0	62.2	7.7	59.8	40.2	0	56.5	43.5	0
16	50.5	38.1	11.3	-	-	-	43.1	47.3	9.6	32.1	52.6	75.4
17	25.4	42.1	32.6	-	-	-	23.7	46.2	30.2	17.5	51.2	31.3
18	.5	43.2	56.2	0	47.7	52.3	7.3	42.8	49.9	2.2	49.7	48.1
19	0	25.2	74.8	-	-	-	0	33.0	67.0	0	36.1	63.9
20	0	23.4	76.7	-	-	-	0	34.4	65.7	-	-	-
21	0	25.8	74.1	0	30.3	69.7	0	33.6	66.4	-	-	-
22	0	25.7	74.3	-	-	-	0	35.2	64.7	-	-	-
23	0	25.8	74.2	-	-	-	0	36.1	63.9	-	-	-
24	0	23.5	76.6	0	24.7	75.3	0	38.4	61.5	-	-	-

U = Unstable
N = Neutral
S = Stable

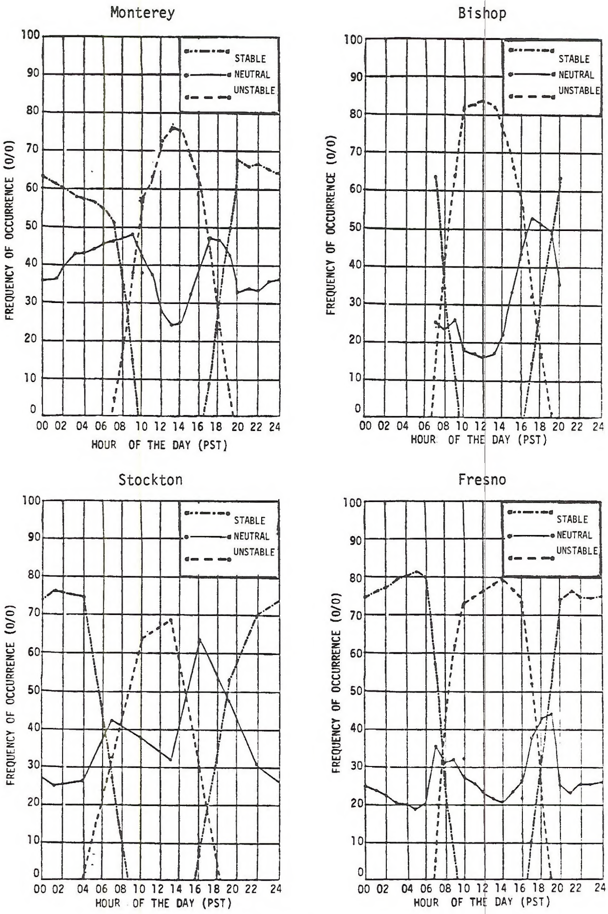


Figure 4.5-7

Diurnal Distribution of Atmospheric Stability in the Folsom District

of the persistence of adverse dispersion conditions. For example, long periods of very stable conditions, will maximize the impact of vehicular emissions. In this way, adverse dispersion conditions can be related to specific pollutant sources.

Table 4.5-2 presents the stability persistence tables for the four stations for which digitized data are available in the Folsom District. These tables are provided for the respective periods of record for each station and are representative of a typical annual period. The values in the tables reveal the percentage of time that a given stability class persisted for a given number of hours at each station.

4.5.4 Stability Wind Roses

Stability wind roses provide information useful for determining land use alternatives in terms of the probable transport and dispersion of airborne pollutants. The data are presented for three major classes which represent a combination of the Pasquill categories; (1) unstable (A-C), (2) neutral (D) and (3) stable (E-G). As noted earlier, maximum ground level pollution impacts vary with each stability category as well as with source emission types and levels.

Once again, stable conditions are generally characterized by light winds, hence, wind roses for this stability category are valuable in determining probable levels and areas of maximum impact from the low-level, non-buoyant emissions associated with many rural land uses, such as grazing and farming. Alternatively, neutral conditions with high wind speeds or unstable conditions can result in maximum impacts from elevated plume sources associated with heavier industrial activity.

Figures 4.5-8 through 4.5-10 provide stability wind roses as well as the annual wind rose for Monterey, Stockton and Bishop in the Folsom District. As indicated earlier, stability class I refers to unstable conditions, stability class II refers to neutral conditions, and stable conditions are represented by stability class III. Each of the stability wind roses can be summed for comparison with the annual wind rose also depicted on each figure.

Figure 4.5-8 indicates that at Monterey, unstable conditions occur almost exclusively with onshore, northwesterly flow. This results from the fact that unstable conditions at Monterey as well as at all other stations, occur during the daylight hours as a result of surface heating. During the daylight hours, Monterey is characterized almost exclusively by onshore flow as the sea breeze regime develops, hence the relationship between unstable conditions and onshore flow at this station. Neutral conditions also occur with onshore flow. Neutral stability is generally indicative of good atmospheric mixing and is usually associated with stronger wind speeds than those experienced during unstable conditions. Finally, stable

Table 4.5-2
Persistence of Stability Class
(Percentage of Total Observations)
in the Folsom District

No. of Hours Stability Persisted	Fresno			Stockton*			Monterey			Bishop		
	U	N	S	U	N	S	U	N	S	U	N	S
1	7.1	3.4	9.9	11.6	6.1	6.9	25.3	36.8	37.1	49.9	31.2	19.0
2	7.8	2.2	8.9	-	-	-	18.7	33.6	31.4	35.3	26.0	10.8
3	5.5	1.8	7.3	-	-	-	13.0	31.1	27.5	21.3	23.0	4.7
4	3.5	1.3	5.4	8.5	5.9	11.9	8.8	29.1	24.7	11.8	19.8	1.8
5	2.4	1.4	3.8	-	-	-	5.1	27.2	22.4	6.2	16.6	0
6	1.4	.8	2.9	-	-	-	3.0	25.5	20.6	3.0	13.6	0
7	1.0	.8	1.8	3.0	4.2	7.3	2.0	24.1	18.8	1.6	10.6	0
8	.3	.8	1.2	-	-	-	.8	22.8	17.0	.3	8.4	0
9	.4	.9	.8	-	-	-	.2	21.5	15.4	0	7.1	-
10	.1	.8	.4	1.0	2.9	4.0	.1	20.4	13.6	0	6.2	0
11	0	.7	.3	-	-	-	0	18.9	11.6	0	5.1	0
12	0	.9	.2	-	-	-	0	17.7	9.4	0	4.4	0
13	0	.6	.2	0	2.3	3.4	0	16.7	7.5	0	3.5	0
14	0	.6	0	-	-	-	0	15.3	5.3	0	0	0
15	0	.5	0	-	-	-	0	13.9	4.1	0	0	0
16	0	.5	.1	0	.9	.8	0	12.5	2.2	0	0	0
17	0	.4	0	-	-	-	0	11.4	0.9	0	0	0
18	0	.7	0	-	-	-	0	9.9	0	0	0	0
19	0	.4	0	-	1.4	0	0	8.6	0	0	0	0
20	0	.4	0	-	-	-	0	7.6	0	0	0	0
21	0	.2	0	-	-	-	0	6.4	0	0	0	0
22	0	.2	0	0	.7	0	0	5.6	0	0	0	0
23	0	.5	0	-	-	-	0	5.2	0	0	0	0
24 or more	0	.2	0	-	-	-	0	4.6	0	0	0	0

* Persistence of 3-hour observations

U = Unstable
N = Neutral
S = Stable

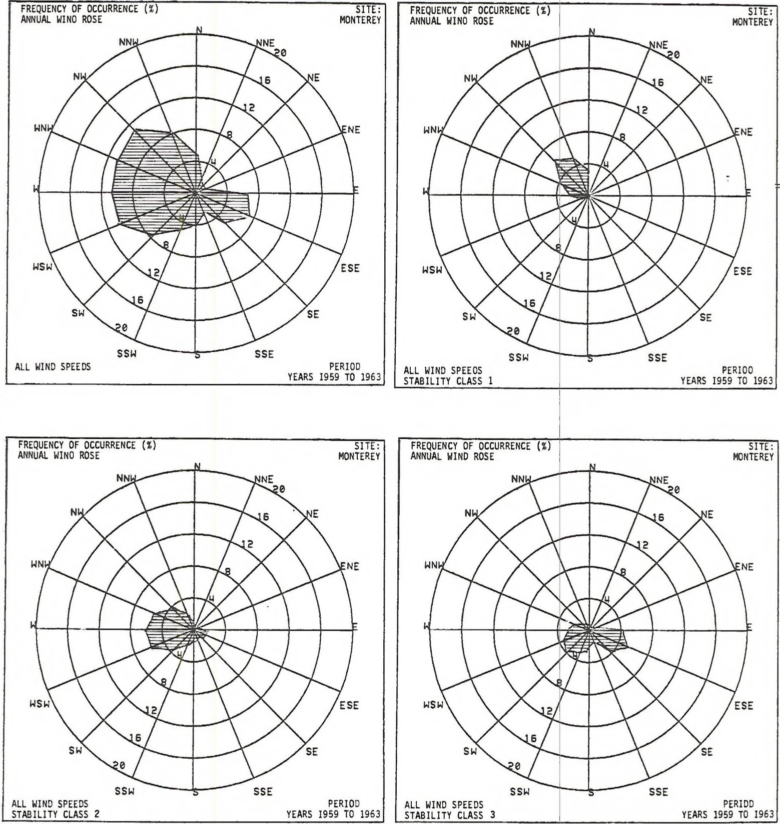


Figure 4.5-8

Stability Wind Roses for Monterey, California

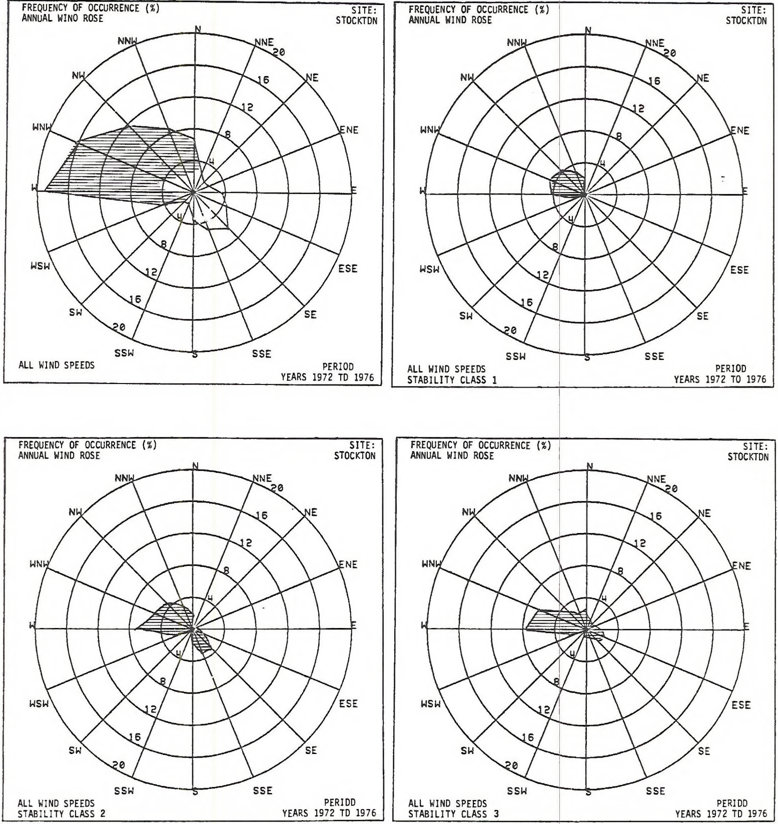


Figure 4.5-9

Stability Wind Roses for Stockton, California

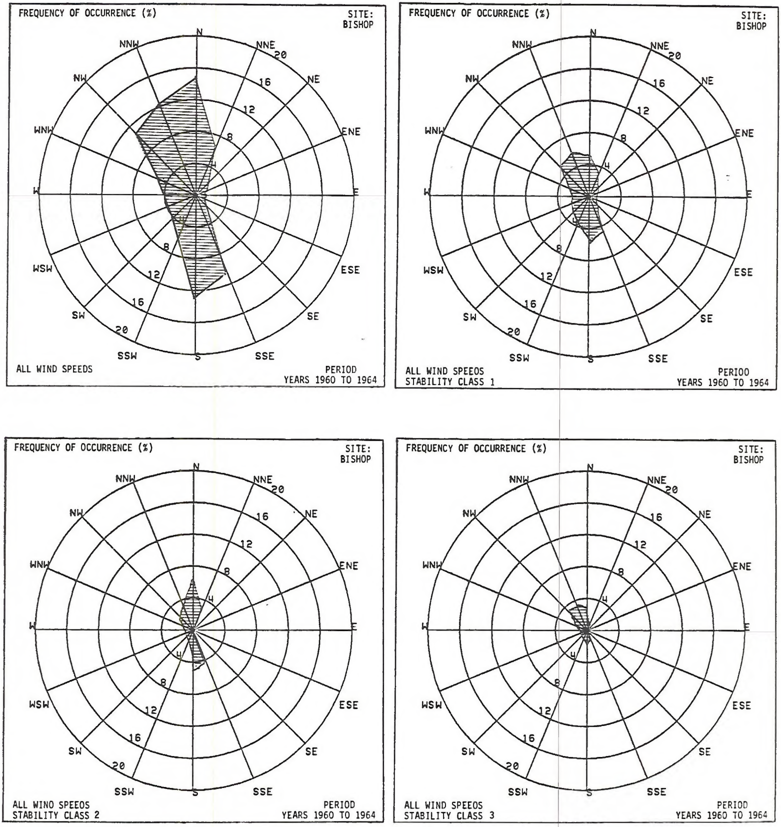


Figure 4.5-10
Stability Wind Roses for Bishop, California

conditions are generally indicative of nocturnal drainage flow regimes. At Monterey, this results primarily from flow from the east-southeast. The wind rose for stable conditions at Monterey also shows a secondary maxima for flow from the southwest. This may represent drainage flow reaching Monterey from the Big Sur area as well as instances of stable onshore flow. This same general pattern can be seen on Figure 4.5-9 for Stockton. Terrain plays an important role for stable flow and the stable wind roses for Monterey and Stockton exhibit the largest variations due to local terrain effects.

At Bishop, Figure 4.5-10 indicates that winds tend to be bimodal on an annual basis with flow generally along either a north-northwesterly or south-southeasterly axis which describes the configuration of the Owens and Long Valleys. The data show little difference in terms of stability class as far as preference for a particular direction.

In summary, stable conditions are generally associated with nocturnal drainage regimes while unstable conditions are associated with the development of either the sea breeze or heating induced upslope flow during the daylight hours. Stronger wind speeds, typical of neutral conditions, tend to be associated with the sea breeze regime or strong synoptic systems.

4.6 MIXING HEIGHTS AND INVERSIONS

The entire atmosphere, is not available for the dilution of pollutants released near the surface. Only the mixing layer which, in many situations may be only several hundred feet thick, can serve this function. Section 4.2.3 describes mixing heights and inversions in considerable detail relative to their role in dispersion meteorology.

This section shall investigate the characteristics of the mean mixing layer throughout various areas of the Folsom District. In addition, inversion statistics will be presented for various locations in the study area, and the subsequent discussions shall provide a review of inversion types and their frequency in the Folsom District.

4.6.1 Mixing Height

Considerable variation in mean mixing heights occurs on a seasonal basis. Throughout the United States, mixing heights vary from several hundred feet on winter mornings to well over 13,000 feet on summer afternoons. In California, the mean annual range is roughly between several hundred feet and approximately 10,000 feet. The variation in mixing heights over a given area can play a major role in pollutant dispersion for certain types of sources. For example, power plant siting is very dependent on regional dispersion characteristics. An area with a history of shallow or low mixing heights would tend to trap pollutants emitted by such a facility. Such an area would therefore be rated as unfavorable for power plant siting.

Mixing depths can be characterized for each air basin in the district. Along coastal locations, morning and afternoon mixing heights are typically at a minimum during the winter season and quickly reach peak levels during the spring months. In the Central Valley, seasonal mixing height variations follow a similar pattern but exhibit slight differences. Afternoon and morning mixing heights in these areas typically reach maximum levels during the late spring and the early summer months. However, the average morning mixing heights are at a minimum during the winter months.

The mean morning mixing height is generally lower at inland areas in comparison with typical mixing depths over the coastal locations. Mean afternoon mixing heights are typically higher in the Central Valley than along the coast, with the exception of the winter season. During this season, afternoon mixing heights are typically the same depth or slightly deeper at some coastal locations particularly in the northern portion of the Distrtict.

Table 4.6-1 provides seasonal and annual mean morning and afternoon mixing height values for selected stations throughout the Folsom District. These statistics were based on temperature sounding data representing at least a continuous five year

Table 4.6-1
Mean Morning and Afternoon Values of
Mixing Height (Meters)*in the Folsom District

	Morning/Afternoon				
	Winter	Spring	Summer	Fall	Annual
Fresno[1,2]	276/656	259/1589	213/1517	208/1138	239/1230
Sacramento[1,2]	300/950	282/1900	223/1700	249/1400	263/1488
Salinas[1,2]	341/700	504/1100	529/650	385/800	439/813
Oakland[3]	453/709	763/1121	527/644	508/770	563/811

* 1 meter = 3.28 feet

1. Based on Air Resources Board data covering a five year period from July 1, 1972 to December 31, 1977.
2. Afternoon mixing heights determined from interpolation of seasonal mixing height analysis from Holzworth's "Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States".
3. Data base from Oakland, California (January 1960 - December 1964) available through the National Weather Records Center in Asheville, North Carolina.

recording period. Figure 4.6-1 provides mean annual morning and afternoon mixing depths for the locations discussed in Table 4.6-1. It is evident from this figure that mixing heights tend to be higher along the coast during the morning hours and in the Central Valley during the afternoon. There is also a tendency for mixing heights to be slightly higher in the northern portion of the District.

Long-term mixing height and inversion data are not currently available for the Sierra Nevada. As a result, interpolative estimates must be made from meteorological data from nearby locations in order to provide a reasonable evaluation of mixing height levels over mountainous terrain.

The steepness of windward mountain slopes and numerous meteorological parameters such as wind velocity, wind direction and atmospheric stability impact mixing height depths and their variability over rugged complex terrain. Figure 4.6-2 through 4.6-4 illustrate mixing layer alterations due to mountain flow for three hypothetical scenarios which vary atmospheric stability. As depicted in Figure 4.6-2, when the lower atmosphere is neutrally stratified, the inversion layer, which is the major determinant of the local mixing depth, tends to follow the contour of the local terrain. Hence, mixing height depths, as defined earlier, remain unchanged or tend to be slightly shallower over the mountainous area.

On the other hand, when a stable surface air mass is capped by an elevated inversion and is forced to rise over abrupt mountainous terrain, considerable variations in the characteristic mixing depth develop. The low lying, stable air is not easily displaced upward and over the mountain ridge; consequently, the surface air mass tends to pile up along the windward mountain slopes, thus forming a bulge in the atmospheric mixing layer just upwind of the mountain ridge. Under these conditions, as depicted in Figure 4.6-3, the mixing depth tends to be larger along the windward slope than along the valley floor or the leeward side of the mountain range.

Figure 4.6-4 presents the situation in which a surface unstable layer is isolated from the upper atmosphere by a lifted inversion. As flow moves over rugged terrain, dramatic changes in the mixing layer can occur. Basically, the low lying, unstable air is forced to ascend into and through the inhibiting inversion layer as surface air flow is swept up the steep western slopes of the Sierra Nevada. This forced convective activity sometimes has the potential to completely wipe out the local inversion layer (or considerably weaken the stable layers) thus promoting considerable mixing of the lower lying air masses. Under such conditions, considerable cloudiness can develop and, at times, much precipitation. This is indicative of summer season conditions resulting in convective thundershower activity. As the flow passes over the mountain ridge and descends down the leeward slopes, the stable layer can once again develop.

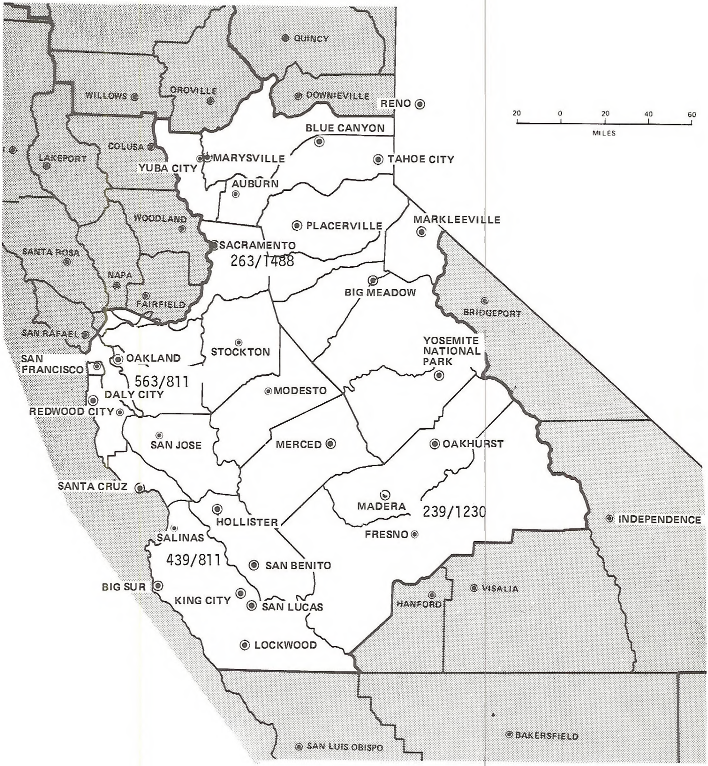


Figure 4.6-1

Annual Morning and Afternoon Stations (AM/PM) Mixing Heights*

for Selected Stations in the Folsom District

* 1 meter = 3.28 feet

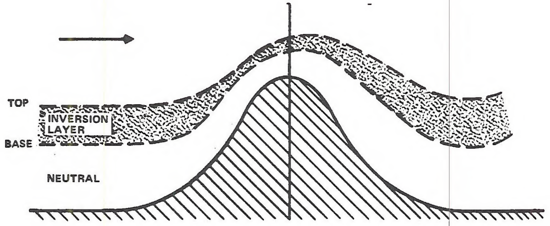


Figure 4.6-2
Depth of the Mixing Layer in Mountainous Terrain with Neutral Flow

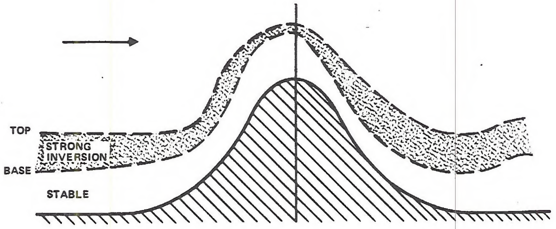


Figure 4.6-3
Depth of the Mixing Layer in Mountainous Terrain with Stable Flow

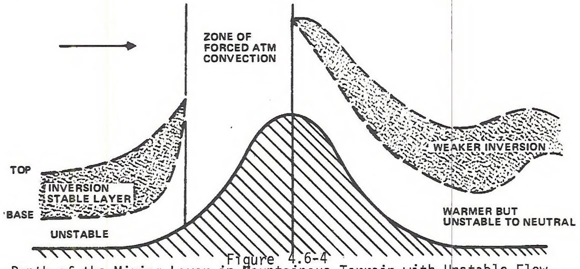


Figure 4.6-4
Depth of the Mixing Layer in Mountainous Terrain with Unstable Flow

The above discussion qualitatively depicts mean mixing height characteristics when flow is forced over mountainous terrain features such as the Sierra Nevada. However, definitive analyses are needed to support the qualitative review presented for this area. Therefore, estimates and assessments of mixing layer depths over these areas are presently best determined by (1) the Holzworth document entitled: "Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States" and (2) the CARB data summarized in "Meteorological Parameters for Estimating the Potential for Air Pollution in California." Seasonal and annual mixing depth contour maps provided by the Holzworth publication are depicted in Appendix C. These figures also present an excellent means for comparing California mixing depth characteristics with other areas of the United States.

4.6.2 Inversion Types and Frequencies

The type and frequency of temperature inversions plays an important role in the overall description of the regional dispersion meteorology of the Folsom District. Basically, inversions are either surface based or elevated with differing impacts on potential pollutant sources. Surface based inversions result in a layer of stable air close to the ground usually with very light wind speeds. This type of situation tends to maximize the impact of ground level non-buoyant sources such as vehicles (e.g. off road vehicles [ORV]) and fugitive sources (e.g. storage tanks, dirt roads, etc). Elevated inversions tend to limit the volume of air available for the mixing of pollutants and tend to maximize the impact of buoyant elevated sources, such as power facilities, refineries, etc. The following paragraphs provide a review of the type and frequency of inversions experienced in the Folsom District.

As indicated earlier, upper air data are only routinely available for Oakland, California. These data have been supplemented by special studies conducted largely by the CARB at Sacramento, Fresno, Merced and Salinas in the Folsom District. The most complete data are available for Oakland as summarized in Table 4.6-2.

At Oakland, as at the other stations, surface inversions generally dominate the distribution during the early morning hours. They occur most frequently during winter and fall at 66.4% and 52% of the time, respectively. Elevated inversions are more common during the afternoon hours with the mean base height of such inversions varying seasonally. During winter, and spring, the base of elevated inversions occurs most frequently between 3000 and 5000 feet. During summer and fall, elevated inversions dominate both the morning and afternoon distributions, occurring primarily between 300 and 800 feet.

Table 4.6-2

Frequency of Occurrence of Temperature

Inversions as a Function of Base Height at Oakland, California

(1960 - 1964)

Season	Time (PST)	Base of Inversion (Meters)(1)										
		Surface	1-100	101-250	251-500	501-750	751-1000	1001-1500	1501-2000	2001-2500	2501-3000	None
Winter (Dec. - Feb.)	0400	66.4*	0.7	3.6	3.6	4.3	2.9	2.7	2.0	2.2	1.3	10.3
	1600	5.4	4.2	7.8	11.8	12.1	8.9	12.7*	6.7	4.5	1.8	24.1
Spring (Mar. - May)	0400	36.4*	0.0	1.3	13.7	12.9	7.0	6.1	5.0	2.6	1.5	13.5
	1600	0.0	3.5	10.2	12.8	8.5	6.3	13.9*	6.3	8.0	1.7	28.7
Summer (Jun. - Aug.)	0400	19.8	1.3	9.6	33.9*	26.1	6.3	1.7	0.9	0.0	0.0	0.4
	1600	0.7	14.0	37.0*	32.2	8.5	2.8	1.8	0.2	0.2	0.4	2.2
Fall (Sep. - Nov.)	0400	52.0*	0.4	3.5	13.0	11.0	5.1	4.2	2.2	1.1	1.3	6.2
	1600	2.0	9.0	17.8*	16.5	7.9	6.8	10.6	5.9	6.4	2.2	14.8
Annual	0400	43.4*	0.6	4.5	16.2	13.6	5.3	3.7	2.5	1.5	1.0	7.6
	1600	2.0	7.7	18.3	18.4*	9.2	6.2	9.7	4.8	4.8	1.5	17.4

Source: Inversion Study, Oakland, California

* Most Frequently Occurring Base Height Interval

(1) 1 meter = 3.28 feet

The inversion data presented in Table 4.6-2 for Oakland provides some characteristic traits which are observed throughout the district. These include the dominance of surface inversions during the morning hours, particularly during the winter and fall months. The sea breeze regime is at a minimum during this period and light stable nocturnal drainage winds tend to dominate, particularly during the night and early morning hours. During the spring and summer months, this effect is less noticeable and the frequency of the surface based inversions decreases. Elevated inversions are a natural result of the presence of the semi-permanent Eastern Pacific high pressure cell. This system results in descending air, thus providing a warmer layer of air aloft, and hence, a temperature inversion. In addition, the sea breeze regime often results in a marine inversion which also produces an elevated temperature inversion particularly at coastal locations. This explains the increased frequency of such fairly low elevated inversion at Oakland during the summer months.

Data for the Central Valley portion of the Folsom District are more sporadic and are generally represented by programs available through the CARB. Tables 4.6-3 and 4.6-4 as well as Figure 4.6-5 provide available historical inversion data for Sacramento, Fresno and Merced.

Figure 4.6-6 indicates the seasonal frequency of surface based inversions during the morning hours in the Folsom District. The summary figure indicates that the frequency of such inversions increases with progression inland from the coast into the Central Valley and southward towards Fresno.

Finally, Figure 4.6-7 provides the seasonal frequency of elevated inversions at Oakland during the afternoon hours. The very limited available data from Sacramento for the fall months indicates that elevated inversions occur less frequently there than at Oakland, most likely reflecting the decreased influence of marine inversions at this inland station.

In summary, surface based inversions dominate the distribution during the morning hours particularly during fall and winter in the Folsom District. This trend is most marked at inland valley locations where the continental (i.e., as opposed to marine) nature of the climate permits the development of these conditions more frequently than at coastal locations. Elevated surface inversions tend to occur most frequently during summer due to the combined influence of the presence of the semi-permanent eastern Pacific high pressure cell as well as marine inversions induced by the nearby presence of cold Pacific water. This latter influence is, of course, most noticeable at coastal locations which have the highest frequency of elevated inversions in the district.

Table 4.6-3

Historical Inversion Data for

Sacramento, California

For the Period 9/71 - 12/73

		Season: Winter	Spring	Summer	Fall
Morning	Percentage (%) Surface Inversions	84	72	52	82
Morning	Percentage (%) Elevated Inversions	16	27	48	17
Afternoon	Percentage (%) Surface Inversions	NA	NA	NA	3
Afternoon	Percentage (%) Elevated Inversions	NA	NA	NA	64

Source: CARB, "Climate of the Sacramento Valley Air Basin".

NA = Not Available

Table 4.6-4

Historical Morning Inversion Data

For Fresno, California

For the Period 7/1/72 - 12/31/77

	Month												
	J	F	M	A	M	J	J	A	S	O	N	D	YR
Percentage (%) Surface Based Inversions	83.5	96.8	96.2	89.3	92.3	89.4	93.8	96.7	98.2	98.2	88.5	86.6	92.8
Percentage (%) Elevated Inversions	16.5	3.2	3.8	10.7	7.7	10.6	6.2	3.3	1.8	1.8	11.5	13.4	7.2
Mean Base Height (FT) for Elevated Inversions	1471	1300	2000	1260	400	633	591	750	500	2333	1924	1439	1217

Source: Franson, Gary, "A Study of the Inversion and Mixing Heights at Fresno, California".

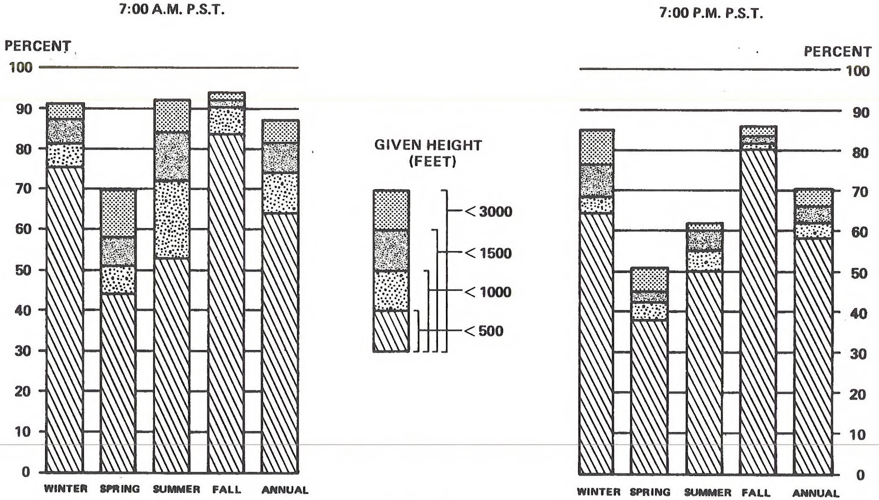


Figure 4.6-5

Seasonal and Annual Morning and Afternoon Values
of Mixing Height at Merced, California

Source: G. C. Holzworth, "Is Valley Weather Conducive to Air Pollution," 1958

Figure 4.6-6
Seasonal Frequency of Surface Based Inversions
in the Folsom District
During the Morning Hours

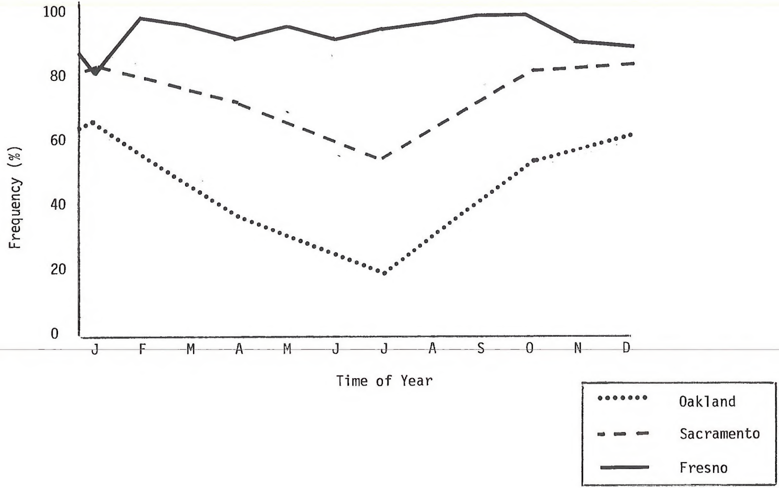
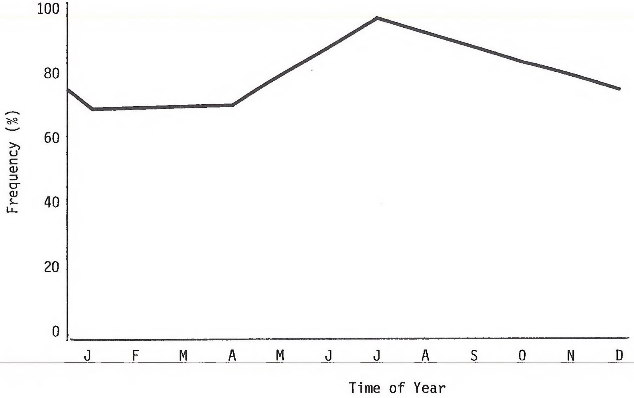


Figure 4.6-7

Seasonal Frequency of Elevated Inversions

at Oakland

During the Afternoon Hours



4.7 TYPICAL AND WORST-CASE CONDITIONS

Previous sections have thoroughly examined and discussed the factors affecting the atmospheric dispersion characteristics of the Folsom District. This permits the identification of typical and worst-case conditions for a variety of typical sources found in the Folsom District. This analysis will provide a basis for determining an initial evaluation of the typical and worst-case impact of various land use alternatives using simplistic modeling techniques as described in Section 4.9.

4.7.1 Typical Dispersion Conditions

Typical dispersion conditions define the most commonly occurring combination of the key dispersion parameters, i.e., wind speed, wind direction and atmospheric stability class. This information is useful particularly in first cut or screening level of effort air quality modeling analyses as described in Section 4.9. In such cases, it is desirable to have a rough estimate of the most commonly occurring dispersion conditions in order to get an indication of the typical impact of an existing or proposed source.

Table 4.7-1 provides a description of the most frequently occurring dispersion parameters for ten sites in or near the Folsom District for which the necessary data are available. These include Bishop, Butte, Diablo Canyon, Fresno, Montezuma, Monterey, Sacramento, Stanislaus, Stockton and Willows. Six of these sources represent data collected by Pacific Gas and Electric (PGE) for proposed or existing generating station sites. These data differ from data collected at the National Weather Service station due to the manner used to determine atmospheric stability class. At the PGE installations, this was done using a temperature difference measurement over discrete height intervals as described by Nuclear Regulatory Commissions (NRC) Regulatory Guide 1.23, as opposed to the method used to generate STAR summaries by the NCC in Asheville, North Carolina. The difference in measurements tends to result in a tendency for unstable conditions to be registered more frequently at sites using the temperature difference method of measurement as opposed to the Pasquill approach. This is apparent from the data presented in Table 4.7-3 which will be discussed in later paragraphs.

The data in Table 4.7-1 provide the most frequently occurring wind direction, wind speed and stability category information suitable for characterizing dispersion meteorological conditions. As such, it is suitable for use in screening level of effort or simplistic modeling calculations to provide a preliminary estimate of existing or proposed pollutant source impacts. The reader is cautioned, however, that dispersion analyses require site specific meteorological data and a more thorough review than that provided by the type of information contained in the table.

Table 4.7-1

Description of Typical Meteorological Conditions[1]

Throughout the Folsom District

Station	Wind Direction	Wind Speed (MPH)	Stability Category[2]
Bishop[3]	N	8.1	1
Butte[4]	SE	8.4	1
Diablo Canyon[4]	NW	8.5	1
Fresno	NW	6.6	3
Montezuma[4]	W	11.5	3
Monterey	NW	5.4	2
Sacramento	SSW	7.5	3
Stanislaus[4]	NW	7.4	1
Stockton	W	8.5	3
Willows[4]	WNW	8.3	1

1. As defined by the most frequently occurring value on an annual basis - parameters are not interrelated, i.e., the indicated wind speed is for the total data base and is not the average for the most frequently occurring wind direction.

2. 1 - Unstable (Pasquill Classes A, B, C)
   2 - Neutral (Pasquill Class D)
   3 - Stable (Pasquill Classes E, F, G)

3. Data only available for the period 0600 - 1900 PST daily.

4. Stability data defined by temperature difference measurements as described in Nuclear Regulatory Commission (NRC) Regulatory Guide 1.23.

4.7.2 Worst-Case Dispersion Conditions

Worst-case dispersion conditions are used by dispersion meteorologists in a screening level of effort to determine the probable maximum impact of an existing or proposed facility. The results of such a review provide an indication as to whether more detailed and sophisticated analyses are required. Once again, as with typical conditions, the worst-case can be defined in terms of the primary dispersion parameters, atmospheric stability class, wind speed and wind direction. The reader is again cautioned in the use of the following information as site-specific data and more detailed analyses are desireable to accurately gage pollutant impact.

In an effort to identify the historical worst-case conditions occurring in California, it was necessary to create a table of five pollutant sources with typical exit characteristics. Table 5.4-1 summarizes typical emission characteristics for fugitive dust, automobiles, oil recovery operations, oil refineries and large power plants. In addition, a traditional worst-case scenario often used by dispersion meteorologists is described. Although the primary pollutants generated from each of these sources may vary, the short-term characteristics of these gases and/or particulates in the atmosphere may be assumed to be highly similar. The five sources listed in Table 5.4-1 represent ground level, non-buoyant; ground level, slightly buoyant; low-level, buoyant; intermediate-level, buoyant; and elevated, buoyant emissions, respectively. Table 4.7-2 lists the worst-case dispersion conditions for each of these sources.

Table 4.7-3 provides the annual frequency of the selected worst-case scenarios for several stations throughout the Folsom District. The table indicates that the selected scenarios for the cross section of sources occur with considerable variability across the area. In addition, the frequency of the scenario selected for one type of source may occur with a substantially different frequency than that selected for another source. This highlights the importance of attaching the probability of occurrence to the selected worst-case meteorological condition for the source in question. The difference in measurement technique is also evident in the data collected at the PGE sites, where the temperature difference technique is used to measure atmospheric stability. These data show a substantially higher frequency of the unstable conditions in a comparison with those observed at the first order NWS stations. All of this highlights the care which must be used in providing an accurate analysis of the probable impact of the source, and the need to involve professional dispersion meteorologists in such programs.

Mixing height, an important parameter in the definition of both typical and worst-case conditions has not been included in the above analysis. This is often difficult to do as real time mixing height data are not generally available concurrently with surface wind speed, wind direction and atmospheric stability

Table 4.7-2
Worst-Case Dispersion Conditions
For a Cross-Section of Typical Sources

Source[1]	Wind Speed (MPH)	Stability Class (Pasquill Class)[2]
Fugitive Dust	1.1	D
Automobiles	1.1	D
Oil Recovery Operations	26.8	C
Oil Refinery	6.7	A
Power Plant	6.7	A
Traditional[3] Worst-Case	2.3	F

1. Reference Table 5.4-1 for a description of the exit characteristics for the sources listed below.

2. Section 4.5 provides a complete discussion of atmospheric stability.

3. In theoretical or "back of the envelope" calculations, this case is often used by meteorologists to describe worst-case conditions.

Table 4.7-3

Annual Frequency (%) of Worst-Case Meteorological Conditions(1)

Throughout the Folsom District

Worst-Cast Condition (St.Class/Wind Speed [MPH])	Station Bishop	Butte*	Diablo Canyon*	Fresno	Montezuma*	Monterey	Sacramento	Stanislaus*	Stockton	Willows*
F and 2.3	4.6	Neg.+	0.2	13.0	1.3	2.0	13.9	0.4	7.0	Neg.+
D and 1.1	0.6	0.6	1.4	0.5	Neg.+	13.0	2.9	2.9	2.5	0.9
C and 26.8	Neg.+	Neg.+	0.1	0.0	Neg.+	Neg.+	Neg.+	0.1	Neg.+	0.1
A and 6.7	1.9	15.0	10.7	1.7	0.4	0.5	0.6	9.9	0.4	17.0

1. As defined for the sources indicated in Table 4.7-2 and described in Table 5.4-1.

\+ Neg. = Negligible but non-zero.

* Stability data defined by temperature difference measurements as described in Nuclear Regulatory Commission (NRC) Regulatory Guide 1.23.

class data to provide for meaningful analysis. However, typical mixing heights can be obtained from the data presented in Section 4.6.1, while historical worst-case mixing heights are discussed by Holzworth in his publication "Meteorological Episodes of Slowest Dilution in Contiguous United States".

4.8 AIR BASIN ANALYSIS

The State of California encompasses an extremely large land area which exhibits a wide variety of geographic and topographic features (see Section 2). As air masses migrate into California, the prevailing winds and dispersion characteristics are greatly influenced by terrain. The degree and nature of the influence can be characterized for geographically and/or meteorologically homogeneous areas. Such zones of similar atmospheric dispersion characteristics can be identified as air basins. Figure 4.8-1 provides the results of an air basin analysis for California while Figure 4.8-2 presents a summary map of the air basins located within the Folsom District of California. The figures represent an original analysis independent of political boundaries and are, therefore, slightly different than the CARB air basin map for the State. The latter figure is also provided as Overlay F.

Air basins provide a means of isolating particular areas of the state that generally exhibit similar atmospheric flow, ventilation mechanisms and dispersion potential. As presented in the figure, these areas include:

- North Coastal Air Basin
- North Coastal Mountain Air Basin
- North East Hills Air Basin
- Mountain Area Air Basin
- Sacramento Valley Air Basin
- San Joaquin Valley Air Basin
- San Francisco Bay Area Air Basin
- Central Coast Air Basin
- Central Coastal Mountains Air Basin
- South Coastal Air Basin
- South Coastal Mountains Air Basin
- Great Basin Valley Air Basin
- South East Desert Air Basin

The development and use of an air basin classification scheme requires one to visualize the atmosphere as a moving fluid washing over mountain ridges and spilling into valleys and through canyon areas. As indicated above, physically and meteorologically homogeneous areas can be then identified and used in dispersion analyses. Regional terrain characteristics generally establish the boundaries of such areas. Terrain features are dominant in establishing air basins as mountain ranges and valleys obstruct or alter regional flow and, hence, dispersion conditions. Figure 4.8-1 illustrates the importance of terrain features in defining meaningful air basins.

While air basins are characteristically defined by major regional terrain features, the climatological and dispersion meteorological conditions existing in the area in question also provide considerable information relative to the identification of homogeneous air basins. An area can be homogeneous from a

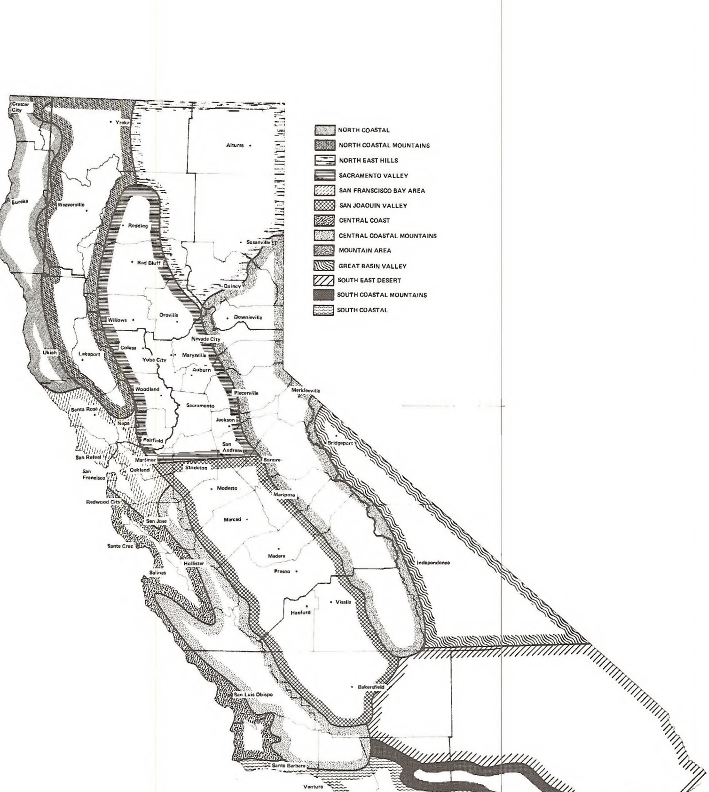


Figure 4.8-1
California Air Basins

terrain standpoint but may vary significantlly in terms of the actual dispersion meteorology. For example, in California, a case could be made for including the Mojave Desert and Owens Valley into one air basin as defined by the terrain characteristics of this general region. However, it is known that the dispersion meteorology is considerably different in the lee of the Sierra Nevada in the Owens Valley as opposed to that experienced in the Mojave Desert. As a result, the Great Basin Valley has been delineated as a separate entity from the South East Desert air basin. Substantially different dispersion meteorological characteristics, such as important differences in prevailing winds, wind speed, atmospheric stability, and mixing heights dictated this decision in the absence of important terrain considerations.

An air basin analysis provides considerable insight into the potential impact of air pollutant emissions within certain regional areas. Particular air basins may ventilate air pollutants very slowly while others do so quite quickly. A detailed discussion of the dispersion characteristics for each air basin in the Folsom District follows.

The Folsom District includes portions of 6 of the 13 California air basins as depicted in Figure 4.8-2. They include:

- The San Francisco Bay Area Air Basin
- Central Coastal Air Basin
- Central Coastal Mountains Air Basin
- San Joaquin Valley Air Basin
- Sacramento Valley Air Basin
- Mountain Area Air Basin

Along the central California coast, flow is predominantly from the west and west-northwest. This flow is dominant in the Central Coastal air basin. Marine air moving onshore is initially influenced by the abrupt coastal terrain and channeled, at the surface, along various coastal valleys and canyons. At District areas south of Monterey, the coastal terrain is steep, rugged and generally mountainous. These physiographic features tend to increase the turbulent mixing of surface air masses as flow from the ocean surface layer (0-300 feet) is forced to rise upward over the abrupt coastal terrain and through coastal canyon areas in the Santa Lucia Range. Mixing depths in this air basin typically range from 700 to 2200 feet with mean surface wind speeds on the order of 6-8 miles per hour as indicated by data available for Salinas.

Marine air impacting coastal areas between Santa Cruz County and Monterey is channeled into the narrow Salinas Valley along the longitudinal axis of the valley floor. This valley has only a slight upslope with inland movement allowing the channeling of the marine flow inland without abrupt or sudden interruption. Dispersion is good along the coastal areas and inland to a point southeast of Salinas. Towards the southeastern end of

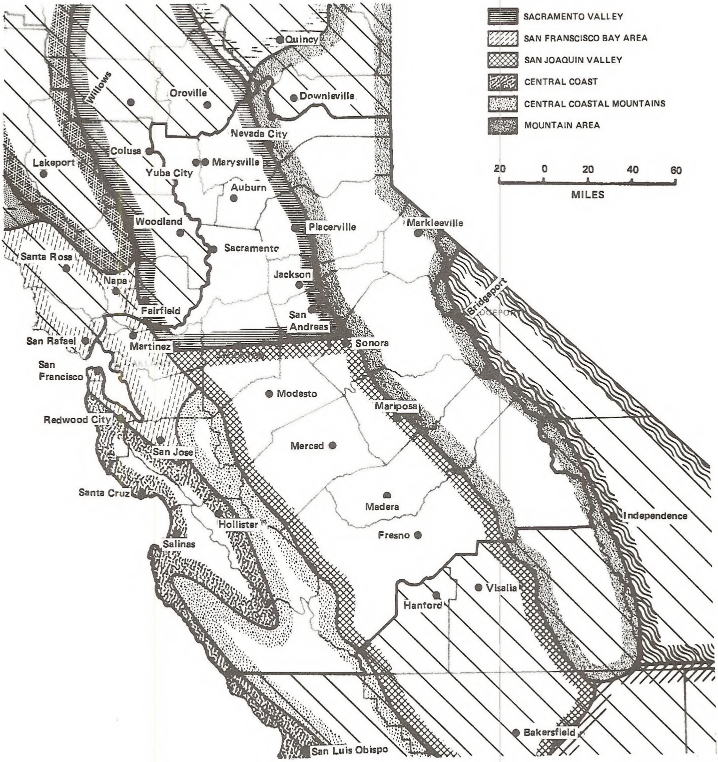


Figure 4.8-2
Air Basins in the Folsom District

the valley, dispersion potential tends to degrade, as the bulk of the air flow becomes trapped as it migrates up and over the Santa Lucia Range and the Sierra de Salinas Mountains and remains well above the valley floor before proceeding eastward over the Coast Range. This situation is known as decoupling and is an important aspect of dispersion meteorology. The condition refers to the lack of vertical transfer as different meteorological regimes develop as a function of height.

Nocturnal drainage flow is often experienced along the coastal regions. During clear nights, rapid radiational cooling of inland surfaces, tends to stabilize the atmosphere promoting air flow from high terrain towards low lying areas. In the coastal air basins, the diurnal sea breeze regime is most prevalent and allows good ventilation potential.

The ventilation potential is excellent within the Central Coastal Mountains Air Basin. Wind speeds are generally high providing a mechanism for rapid flushing of pollutants. During periods of atmospheric stagnation, flow can drain from the highest levels into the San Joaquin Valley Air Basin and simultaneously into the Central Coastal Air Basin as stable conditions dominate.

The San Francisco Bay Area has been isolated as a separate air basin. Marine flow from the west and west-northwest is channeled directly inland over the San Francisco area. As marine surface flow enters the Bay area, it is channeled along the two major axes of the San Paolo and San Francisco Bays. The San Paolo Bay leads eastward through the Carquinez Straits into the San Joaquin Valley while the San Francisco Bay leads southeastward into the Santa Clara Valley.

The Santa Clara Valley is bordered to the east by the Diablo Range and to the west by the Santa Cruz mountians. A marine environment dominated by the sea breeze describes the southern Bay Area air basin. Mixing depths are generally 1000 to 2600 feet, being slightly lower during the morning hours and higher during the afternoon. Mean wind speeds in the area range from 8 to 10 mph.

The major stream of marine air into the San Francisco Bay Area passes inland and follows the San Paolo Bay eastward passing through the Carquinez Straits as a strong westerly wind. This air stream then diverges over the delta area, channeling northward into the Sacramento Valley and southeastward into the San Joaquin Valley.

Dispersion and ventilation potential are generally similar in the Sacramento and San Joaquin Valleys but notable differences do occur in mixing depths and mean surface flow. This suggests that the two areas should be isloated into separate air basins on the basis of known differences in dispersion meteorology.

In the Sacramento Valley Air Basin, mixing depths range from 650 to 1300 feet during the morning hours and extend to as high as 4600 to 5200 feet during the afternoon. Ventilation potential improves as one moves northward. Wind speeds near Sacramento are typically 7-9 miles per hour; whereas, in the northern portion of the valley, the dispersion potential improves as the mean wind speeds reach roughly 10 miles per hour.

In the San Joaquin Valley Air Basin, dispersion potential decreases towards the south. Mixing heights over Fresno, in comparison with Sacramento, are generally 100 to 160 feet lower in the morning and 800 to 1000 feet lower during the afternoon hours. Wind speeds tend to decrease with southward progression as well. Stockton reports a mean wind speed of 8.1 miles per hour, whereas Fresno registers a mean annual wind speed of only 6.3 miles per hour.

Downvalley drainage flow during the nocturnal hours is more dominant in both Central Valley air basins as winter approaches. During winter, the nocturnal air flow is almost entirely from the southeast in the San Joaquin Valley and primarily from the north in the Sacramento Valley. Air flow from these air basins converges in the delta region to form a strong easterly flow into the San Francisco Bay Area. This flow can interact with onshore sea breezes along the coast causing complex wind patterns and high pollutant levels in the Bay Area.

The Mountain Area air basin borders the eastern extent of the San Joaquin Valley air basin. These mountain areas are comprised of extremely steep and rugged terrain. Many locations in this air basin are higher than the mean elevated inversion levels generally experienced over the Central Valley. However, many minor air basins exist in the mountain areas, and some isolated areas are surrounded by towering mountains. In such areas, including Tahoe and Lake Amador, dispersion of air contaminants can be greatly inhibited. On the other hand, at mountain peaks and other well exposed locations, the ventilation characteristics are generally excellent since the wind flow is basically uninhibited by surrounding physiographic features.

4.9 FIRE WEATHER

The primary purpose for the utilization of open burning is to quickly eliminate choking underbrush, for example, in the management of forested lands, or to dispose of waste vegetative growth in the management of agricultural areas. These goals must be accomplished while causing a minimum impact upon ambient air quality in the surrounding region. For this reason, it is desirable to achieve a quick, hot burn which will result in a minimum burn time, while maximizing the atmosphere's dispersive capabilities by getting the resulting smoke well above the surface layer.

Meteorology plays a very important role in the identification of proper periods during which to burn with a minimum impact on surrounding air quality. Burn versus no-burn days are forecasted daily by the CARB for each of the designated air basins in California. Forecasts for the following day are usually available by 1500 PST. If the issuance of a forecast is delayed, they are to be available by no later than 0745 PST on the day in question. The CARB uses some very basic criteria in making decisions relative to open burning in each of California's air basins. The forecasting criteria are designed to isolate those days on which the burning of large surface areas will have a minimum impact on local air quality, based upon the atmosphere's ability to disperse pollutants. Factors which impact this are the stability of the atmosphere, the presence of either surface or elevated inversions and the mean wind speed and wind direction. Previous sections have provided a review of the dispersion meteorology of the Folsom District and reference is made to that discussion for more details relative to these parameters.

The dispersion of smoke generated from open burning is restricted by such features as stable atmospheric conditions, an elevated inversion which restricts the volume of air available for mixing, as well as low wind speeds which result in little movement of the pollutants once they are emitted. These meteorological considerations work hand in hand with the nature of the local terrain. Areas which are in a valley or a bowl and are surrounded by important terrain features tend to trap emitted pollutants near the source particularly when restrictive meteorological conditions combine with such terrain effects. Accordingly, the CARB forecasting criteria include a review of the anticipated strength of the morning surface inversion, the relative stability of the atmosphere from the surface to roughly 3,000 feet, the wind speed at the expected plume height, as well as the probable wind direction. Burning is not permitted on days when wind speeds are light, the atmosphere is stable, strong surface or elevated inversions exist, or if wind directions will tend to blow smoke toward populated areas.

Section 6.5.2 will provide a review of the regulatory constraints involved in open outdoor burning including the acquisition of permits. Once a permit is obtained, the basic decision whether or not to burn is based upon acquiring the burn/no-burn forecast from the CARB in Sacramento. In addition to this, local rules of thumb should be used to provide proper management of the burn in terms of meteorological conditions. The following provides an example of typical considerations:

- The wind direction at the probable plume height should be such that the plume will move away from Smoke Sensitive Areas (SSA). The California Division of Forestry (CDF) has designated SSA's in California which should not be impacted by any burn contemplated by BLM managers. Figure 4.9-1 provides a review of the location of such areas in the state. These regions include most of the populous areas of the state, as well as areas in rugged terrain subject to considerable recreational use.

- Low wind speeds should be avoided, particularly where SSA's may be impacted.

- Wind speeds should generally be greater than 15 miles per hour to maximize dispersion.

- Surface inversions should be avoided due to the potential for trapping the smoke near the surface. However, if the plume is carried above the inversion, the downward dispersion of contaminants will be inhibited by the surface based inversion.

- If the burn will be less than 12 hours, it is beneficial to start in the morning as this will tend to maximize the buoyant effects associated with the burn.

- If the burn is to last more than 12 hours, it may be beneficial to start at night as this may minimize adverse smouldering effects, experienced following the burn.

- Burning in precipitation is advantageous from an air quality viewpoint as much of the contaminants will tend to be washed out of the plume.

- Burning should not be conducted when visibility is less than 11 miles at the site or at a nearby SSA.

- Burning should never be conducted when fire danger exists and the manager should be cognizant of forest fire weather forecasts provided by the NWS.

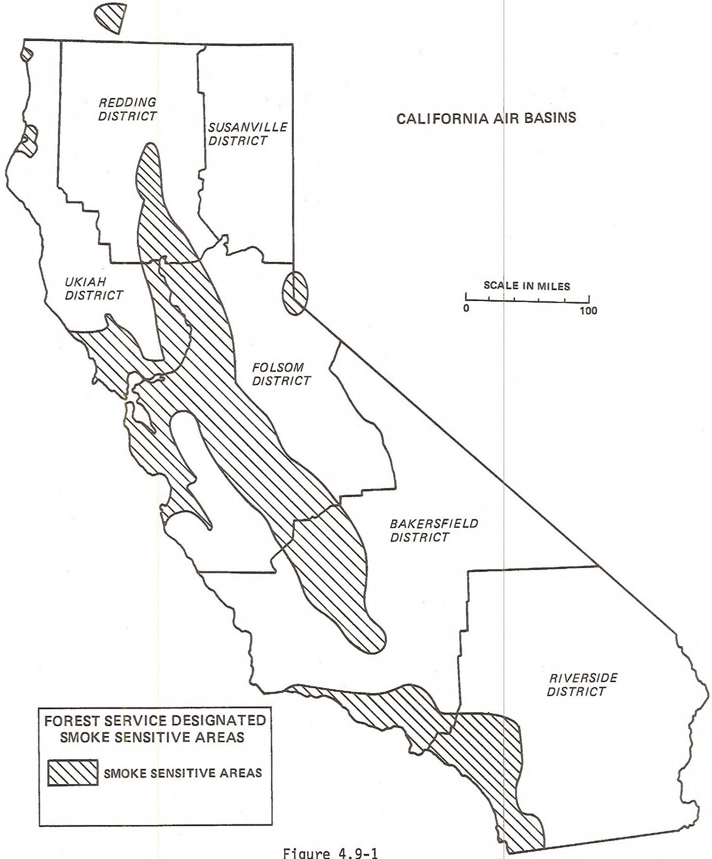

CALIFORNIA AIR BASINS
REDDING DISTRICT
SUSANVILLE DISTRICT
UKIAH DISTRICT
FOLSOM DISTRICT
BAKERSFIELD DISTRICT
RIVERSIDE DISTRICT
SCALE IN MILES
0
100
FOREST SERVICE DESIGNATED SMOKE SENSITIVE AREAS
SMOKE SENSITIVE AREAS

Figure 4.9-1

- The manager should be able to respond to deteriorating conditions so that the burn can be downgraded should dispersion conditions become poor.

- Unlimited burning is never recommended unless the wind direction is away from a SSA, or a SSA is located more than 100 miles away, or if the burn is to be conducted during precipitation. Even in these instances, a quota should be established for the amount of dry fuel to be burned during the day.

- Burning should not be conducted when the wind direction will result in the movement toward a SSA if the area is within 30 miles.

Figures 4.9-2 and 4.9-3 provide a review of typical atmospheric conditions experienced over California during the afternoon and nighttime hours. Figure 4.9-2 displays the terrain of California, including the Coast Range, the Sacramento Valley and the Sierra Nevada. As indicated in the figure, the prevailing wind in this area is from west to east. The atmosphere, close to land areas tends to be unstable during the afternoon hours, while over the ocean and above the unstable air, a very stable regime exists as part of the marine layer induced by the nearby ocean. This generally extends up to nearly a thousand feet during the afternoon. Above that point, the atmosphere is generally slightly stable. Three potential burns are illustrated on the figure; one in the Coast Range, one near the Coast Range, and one in the Sierra Nevada. In addition, the figure depicts a SSA in the populous Sacramento Valley region.

The fire illustrated in the higher elevations of the Coast Range would have a very limited impact in the SSA located to the east. The plume is initially buoyant and is emitted into an unstable atmosphere and will tend to reach an elevation above that of the stable layer. As such, in most instances, it will not have an important impact on the SSA as downward dispersion will be inhibited. The burn illustrated in the lee of the Coast Range at a relatively low elevation would have to be managed very carefully as it is in relatively close proximity to the SSA. Here, the plume is emitted into an unstable atmosphere, but is limited from continued dispersion aloft by the presence of a very stable elevated inversion. As such, the plume does have the potential to impact the SSA and would have to be regulated very closely. The final burn indicated in the figure is well up into the Sierra at a location where it should have an acceptable impact on local air quality. The plume is moving away from the SSA and is benefiting from excellent dispersion effects due to the unstable surface layer as well as the effects imparted by orographic lifting over the higher terrain.

Typical meteorological conditions in California at night are displayed in Figure 4.9-3. In this instance, very stable air tends to accumulate over the SSA, and burning would not be recommended in the zone. Burning at mountaintop locations, however,

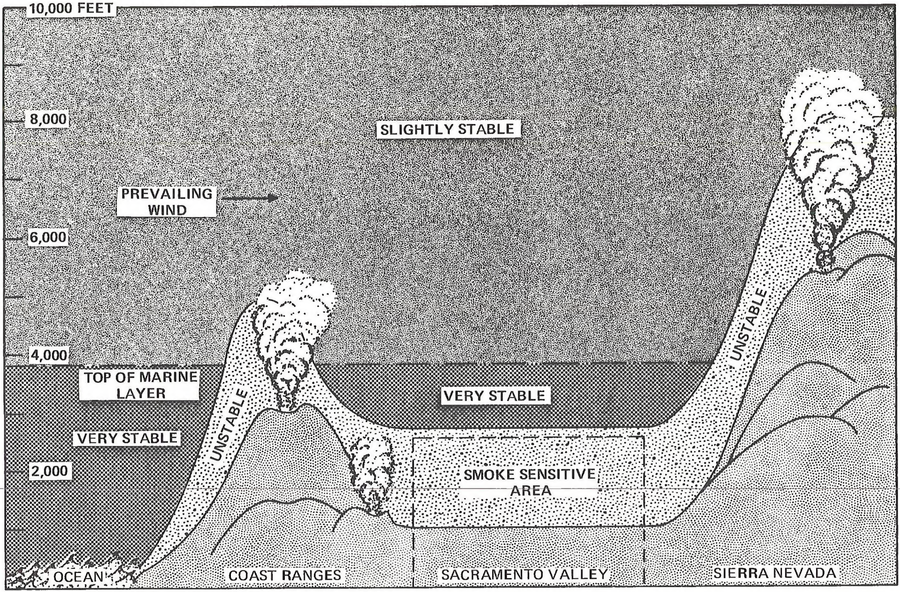


Figure 4.9-2

Typical Afternoon Dispersion Conditions and the Impact on Burning

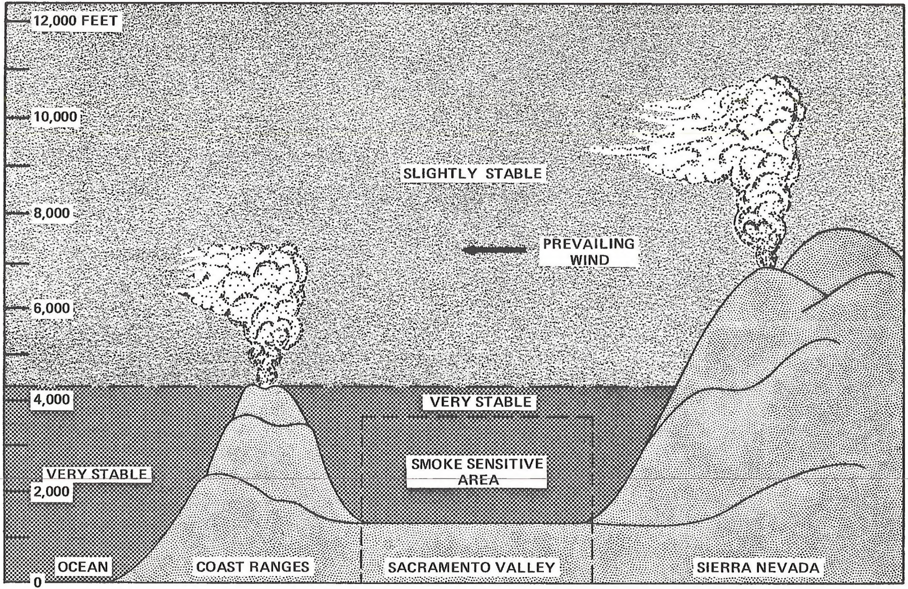


Figure 4.9-3

Typical Nighttime Dispersion Conditions and the Impact on Burning

would still be acceptable as they are being emitted into a slightly stable atmosphere and the very stable layer below would prohibit the downward dispersion of the plume into the SSA. These figures provide only idealized descriptions of typical meteorological effects on potential burn situations. It is emphasized that the decision should be based upon burn/no-burn forecasts available from the CARB, even in areas which are outside the jurisdiction of regulatory agencies due to elevation as described in Section 6.5.2.

4.10 GENERAL DISPERSION MODELING

Dispersion modeling is a mathematical representation or simulation of transport processes that occur in the atmosphere. There are numerous dispersion modeling techniques available, all of which aim to calculate ground level concentrations of pollutants that result from industrial, agricultural, transportation and urban emissions. It is important to realize that there exists no single modeling technique capable of properly depicting all conceivable dispersion situations that occur in the atmosphere. Likewise, meteorological conditions impacting dispersion are complex and depend on the interaction of numerous physical processes. Therefore, any successful modeling effort must be directed by individuals with broad knowledge and experience in air pollution meteorology, as well as expertise in data processing techniques. The judgement of well trained professional analysts is essential to properly evaluate the ground level impact of pollutant emissions. Without detailed validation/-calibration efforts, air quality modeling results are generally felt to be good only within an order of magnitude under many circumstances, such as applications in areas of rugged terrain.

Air quality models have been widely used to identify potential violations of National Ambient Air Quality Standards (NAAQS). Modeling studies of the atmosphere are useful in determining emission limits for industrial development in specified areas. Hence, dispersion models are vital to the timely and cost effective development of air pollution control strategies for most regions. Ideally, mathematical modeling of the dispersion potential of the atmosphere would allow optimum planning for proposed land use development in terms of minimizing the air pollution impact. Dispersion models provide a technique which can be used to help ensure attainment and maintenance of air quality standards and to prevent significant air quality deterioration due to future development.

This section is designed to present a basic understanding of dispersion modeling approaches to air qualtiy problems. The subsections to follow will alllow the reader to understand the concepts of mathematical air quality modeling. Numerous models are described as well as techniques for selecting the optimum approach. English units, which have been employed in previous sections of this document, will not be used here. Calculations must be performed in metric units, as dictated by the equations and figures commonly used in dispersion modeling. English conversions, however, have been placed on figures as a convenient reference for the reader.

4.10.1 Classes of Models

Basically, there are four general types of air quality models available. These types of dispersion models are characterized as:

- Gaussian
- Numerical
- Statistical or Empirical
- Physical

Within each of these classes, there exists a large number of individual computational algorithms, each with its own specific application. For example, numerous air quality models have been developed based upon the Gaussian or log-normal solution to the fluid transport equation. Each particular model or algorithm is designed to handle a specific air quality and atmospheric scenario while computing pollution impacts through the use of the Gaussian diffussion equation. The models may, for example, consider different atmospheric parameters, terrain features, and various degrees of data resolution. The well-known EPA dispersion models such as the Climatological Dispersion Model (CDM), the Air Quality Display Model (AQDM), the Valley Model, and the Texas Climatological Model (TCM) are commonly referred to as individual models but in fact are all variations of the basic Gaussian model. In many cases, the only real difference between models is the degree of detail considered in the input and output of data.

Gaussian models are considered to be the state of the art technique for estimating the impact of non-reactive pollutants. These types of models assume instantaneous transport of effluents downwind of the emission source. However, numerical models are more appropriate than Gaussian models for source applications which involve reactive pollutants. Most numerical models employ numerous interactive steps allowing for downwind adjustments to time dependent chemical and thermal processes that take place in the plume. Statistical or empirical techniques are frequently employed in situations where an incomplete scientific understanding of the physical and chemical processes of the plume behavior makes the use of the Gaussian and numerical modeling approaches impractical. Physical modeling, the fourth generic type, involves the use of a wind tunnel or other fluid modeling facilities necessary to investigate dispersion in very confined, specialized environments isolated to only a few square kilometers. Physical modeling is a complex process which requires a high level of technical expertise.

4.10.2 Model Suitability and Application

The level of analysis for which a particular dispersion model is well suited depends on several factors. These include:

- The detail and accuracy of the data base (i.e., emission inventory, baseline air quality and meteorological data)
- The local topographic and meteorological complexities
- The technical competence of the individuals directing the modeling effort

- Available financial and computational resources

Air quality models require a data base which includes emission source characteristics, meteorological parameters and baseline air quality levels (and at times, local topographic data and temporal statistics). Models that require detailed and precise input data should not be applied when such data are unavailable.

Most dispersion models are intended for use only in areas of relatively simple topography. Specific modeling analyses for major topographic features and complex meteorological scenarios may start with a simplistic preliminary screening analyses using the Gaussian or other straightforward approach to define the level of impact. If these analyses point to a potentially important impact then more sophisticated modeling approaches must be implemented.

Applications of the various classes of air quality models previously mentioned require a two step approach with various levels of sophistication. The first level consists of general techniques that provide relatively simple and conservative estimates of air quality impact of a specific source or source category. This initial screening level, provides an understanding of air pollution impact due to a particular source(s) in the area in question. The major objective at this stage is to identify potential violations of air quality standards. This is done by using simple analytical techniques to isolate areas of projected maximum ground level concentrations for comparison with the most limiting standards, and is the level of effort the District Offices should strive to accomplish.

The second level of effort involves the use of analytical techniques which provide a more detailed treatment of physical and chemical processes once a potential problem has been identified. This step requires a more detailed and precise data base which will result in a more accurate estimate of source impact. At this point, an exhaustive data base specific to the study area is incorporated into the modeling analysis. For example, temporal variations in the baseline meteorology, air quality and emissions data can be input to the model. Emission inventory data can also be more accurately assessed in terms of such aspects as temporal variability.

The screening level approach to air quality modeling is highly recommended in all initial applications of dispersion models. If a problem is identified, then more sophisticated analyses are indicated. In any case, a multi-step approach to modeling is vital in accurately establishing regional air quality impact.

A specific plan of attack is required for each dispersion problem that is encountered. It is not the purpose of this section to recommend specific models for specific air quality

impact situations, but rather to provide a foundation or framework in which to approach the basic air quality modeling problem, which may be used as a screening level to determine if further analysis is needed.

4.10.3 The Gaussian Model

Gaussian based models are considered to be the state of the art technique for estimating concentrations of non-reactive pollutants such as sulfur dioxide and particulate matter for most point source emissions. Numerous experiments have been conducted to study the shape of plumes. The publication "Meteorology and Atomic Energy" lists over twenty experiments, many of which have been conducted by the Atomic Energy Commission (now ERDA-Energy Research and Development Administration). In general, most investigators have been satisfied that a Gaussian distribution is a good mathematical approximation of plume behavior over time periods on the order of five minutes to one hour. Figure 4.10-1 illustrates the Gaussian plume distribution in the horizontal and the vertical.

The Gaussian model provides reasonable estimates in flat or gently rolling terrain. However, Gaussian based models are extremely inaccurate for air quality impact assessments in areas comprised of extremely rugged and varying terrain, such as hilly or mountainous regions. For such situations, statistical or physical modeling methods are best employed, since the dispersion potential of the atmosphere can then be characterized by empirical data obtained by local monitoring programs.

Properly used, a Gaussian model is unequalled as a practical diffusion modeling tool in terms of simplicity, flexibility and the successful correlation between predicted and measured values. For these reasons, the Gaussian model is used in this section to illustrate several simple modeling problems. All variables which will be used to solve the Gaussian equation will now be defined:

$C(x,y,z)$ is the concentration at a point (x,y,z).

$\bar{x}$ is the mean

σ_y, σ_z are the standard deviations in the y and z directions

Q is the emission rate

$\bar{u}$ is the mean wind speed and

H is the height of the plume centerline when it becomes essentially level.

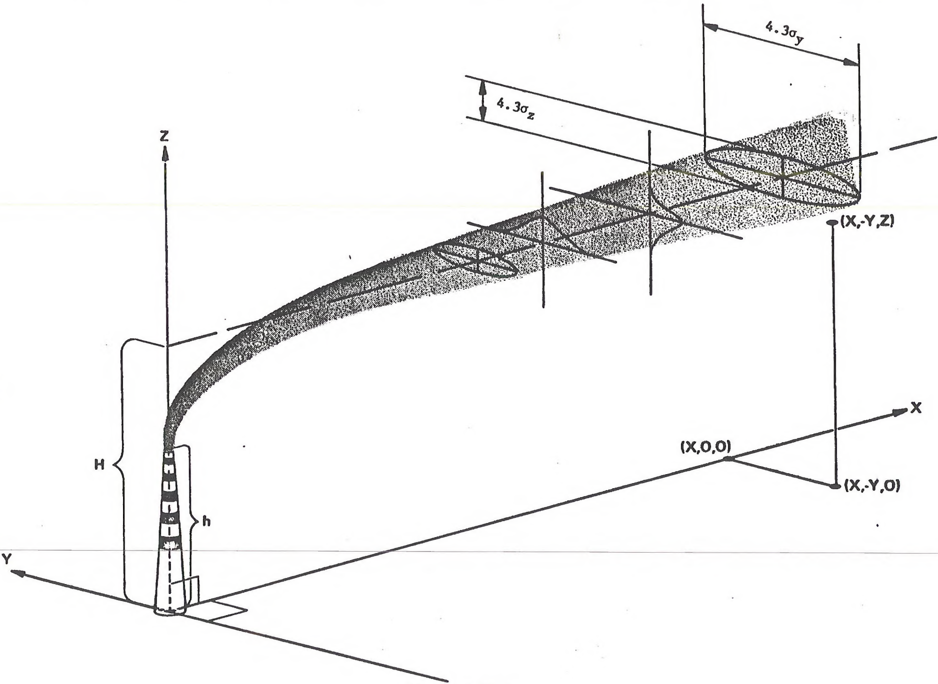


Figure 4.10-1

Coordinate System Showing

GAUSSIAN Distribution in the Horizontal and Vertical

The normal or Gaussian frequency curve is given by:

$$C(x) = \frac{1}{(2\pi)^{1/2}\sigma} \exp - \frac{(x - \bar{x})^2}{2\sigma^2} \qquad 4.10\text{-}1$$

Where C is the concentration, $\bar{x}$, is the mean, and σ is the standard deviation. $(2\pi)^{1/2}$ makes the area under the curve, from $x = -\infty$ to $= +\infty$, equal to 1 (See Figure 4.10-2).

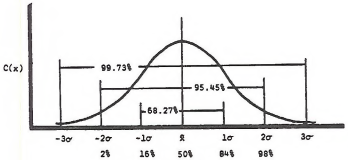


Figure 4.10-2

Gaussian or Log-Normal Distribution

When a distribution is binormal in the two dimensions x and y, the probability density function is:

$$C(x,y) = \frac{1}{2\pi\,\sigma_x\,\sigma_y}$$

$$\exp - \frac{1}{2}\left[\frac{(x - \bar{x})^2}{\sigma_x^2} + \frac{(y - \bar{y})^2}{\sigma_y^2}\right] \qquad 4.10\text{-}2$$

If there is a continuous emission, Q, of gas or aerosols from a point, H, above the ground, a 3 dimensional coordinate system must be defined so that the origin is on the ground beneath the point of emission, x is in the direction of the mean wind, $\bar{u}$, y is crosswind and z is vertical.

Likewise, it is assumed that the diffusion in the crosswind and vertical dimensions will occur in a Gaussian manner, so that the pollution will move downwind with the mean speed of the wind, and that the diffusion in the downwind direction is negligible compared with the transport.

The concentration, C, at any point (x,y,z) can be written as:

$$\frac{C(x, y, z)\,\bar{u}}{Q} = \frac{1}{2\pi\,\sigma_y\,\sigma_z}$$

$$\exp - \frac{1}{2}\left[\frac{y^2}{\sigma_y^2} + \frac{(z - H)^2}{\sigma_z^2}\right] \qquad 4.10\text{-}3$$

Here y is assumed to be 0, and $\bar{z}$ assumed to be H. In this equation, C has units of mass per volume; $\bar{u}$, velocity or length per time; Q, mass per time; σ_y and σ_z length; and y,z, and H, length.

Because diffusion in the z direction is bounded by the earth's surface, equation 4.10-3 cannot be strictly used. If it can be assumed that the ground acts as a perfect reflector, therefore, source at z = H is assumed to have a virtual "image" source at z = -H and

$$\frac{C(x, y, z)\,\bar{u}}{Q} = \frac{1}{2\pi\,\sigma_y\,\sigma_z} \exp\left[\frac{-y^2}{2\,\sigma_y^{\,2}}\right] \left[\exp - \frac{(z-H)^2}{2\sigma_z^{\,2}} + \exp - \frac{(z+H)^2}{2\sigma_z^{\,2}}\right] \qquad 4.10\text{-}4$$

This is the generalized diffusion equation. We cannot expect to obtain instantaneous concentrations from this equation, but concentrations averaged over at least a few minutes time. There are several reasons to expect this equation to be valid for the atmosphere. It obeys the equation of continuity, i.e., the conservation of mass. The mass Q/1 second is found between any two planes perpendicular to the x-axis at a distance $\bar{u}$ /1 second apart. Secondly, diffusion is a random process and the distribution of material from such motion may be expected to be in some statistical form; in this case, according to the Gaussian curve. However, there is one theoretical reason why one would not expect this equation to apply. Diffusion can only occur at a finite speed, i.e., the concentration of released material should drop to zero at some distance from the x axis because it has not diffused to this point. The Gaussian distribution assumes the material to be spread from $-\infty$ to $+\infty$ crosswind. This is not of practical importance, however, as the Gaussian distribution drops off extremely rapidly within a few σ crosswind. One practical limitation is that the Gaussian distribution does not allow for any wind shear in the surface layer.

Interest is generally focused upon ground level concentrations, i.e., C(x, Y, 0). Substituting z = 0 in (4.10-4) yields:

$$\frac{C(x, y, 0)\,\bar{u}}{Q} = \qquad 4.10\text{-}5$$

$$\frac{1}{\pi\,\sigma_y\,\sigma_z} \exp - \left[\frac{y^2}{2\sigma_y^{\,2}} - \frac{H^2}{2\sigma_z^{\,2}}\right]$$

It will be noted that the 2 in the denominator in (4.10-4) is eliminated in (4.10-5) because of the 2

resulting from $2 \exp - \frac{H^2}{2\sigma_z^2}$ occurring in the numerator.

If the source is at ground level (H = 0), there is further simplification. Similarly, if one is interested only in center-line concentrations (directly downwind) then y = 0, and equation (4.10-5) may again be simplified.

This (4.10-5) is the basic equation for calculating the ground level concentration from a continuous point source. The usual units for the variables are:

C (x, y, 0)	gms/m^3
$\bar{u}$	m/sec
Q	gms/sec
σ_y, σ_z, y, H,	meters

As seen from Equation 4.10-5, the plume concentration (C) at various downwind distances (x) from the emission source is largely dependent upon horizontal and vertical dispersion coefficients (sigma y or sigma z). Figure 4.10-1 illustrates the coordinate system for a typical plume and visually describes the significance of the dispersion coefficients in the y and z directions.

Stability

The values of both σ_y and σ_z will depend upon the turbulent structure of the atmosphere. If measures of horizontal and vertical motions of the air are made as with a bivane, the resulting records may be used to estimate σ_y and σ_z (see Pasquill, 1961). If wind fluctuation measurements are not available, estimates of σ_y and σ_z may be made by first estimating the stability of the atmosphere from wind measurements at the standard height of 10 meters, and estimates of net radiation (Pasquill, 1961). Stability categories (in six classes) are given in Table 4.10-1 in terms of insolation during daytime (radiation received from the sun) and amount of cloud cover at night. Strong insolation corresponds to a solar altitude (above the horizon) greater than 60^o with clear skies, and slight insolation corresponds to a solar altitude from 15^o to 35^o with clear skies. Table 170, Solar Altitude, and Azimuth in the Smithsonian Meteorological Tables (List, 1951) is a considerable aid in determining insolation. Cloudiness will generally decrease insolation and should be considered along with a solar altitude in determining insolation. Insolation that would be strong with clear skies may be reduced to moderate with broken middle clouds and to slight with broken low clouds. Night refers to the period from one hour before sunset to one hour after sunrise. The neutral category, (D), should be assumed for overcast conditions during day or night.

Table 4.10-1

Key to Stability Categories

Surface Wind Speed (at 10 m) m/sec	Isolation			Night	
	Strong	Moderate	Slight	Thinly Overcast or ≥ 4/8 Low Cloud	≤ 3/8 Cloud
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

The neutral category, D, should be assumed for overcast conditions during day or night.

Estimation of Vertical and Horizontal Dispersion

Having determined the stability class from Table 4.10-1, the measures of diffusion in the vertical, σ_z, and in the horizontal, σ_y, may be estimated as a function of downwind distance from the source, (x), using Figures 4.10-3 and 4.10-4. These values of σ_z and σ_y are valid for concentrations, (C), averaged over a few minutes time, and apply to open level country with no allowance made for turbulence due to buildings or topography. With very light winds on a clear night, the vertical spread may be less than the values for class F.

When conditions are such that the vertical structure of temperature indicates a definite limit to the vertical convection, particularly under unstable conditions, the σ_z should be allowed to increase only to $0.47h_1$ where h_1 is the limit of convection. At the distance x_1 where $\sigma_z = 0.47\ h_1$, the plume is still assumed to have a Gaussian vertical distribution. It can be assumed that by the time the plume travels twice this distance ($2x_1$), the plume has become uniformly distributed between the earth's surface and the limit of convection. A value of σ_z equal to $0.8h_1$ may be used and the exponential term dropped at distances equal to or greater than $2x_1$ and will make the concentration value computed by the equation, equal to that from a plume uniformly distributed in the vertical.

Estimation of Wind Speed

For mean wind speed, ($\bar{u}$), the value measured at 10 meters elevation (surface wind) should be used for x up to about 1 km for surface sources or short stacks. For greater distances or elevated sources, a mean speed through the vertical extent of the plume (about 2 σ_z) should be used. A speed midway between the surface and geostrophic speeds should be reasonable.

Calculation of Centerline Concentration From a Ground Level Source

For most practical purposes it will be sufficient to calculate the centerline concentration for the distances 100 m, 1 km, 10 km, and 100 km and plot these against downwind distance x, on log/log graph paper for interpolation of concentration for other distances. (For unstable or stable cases it is desirable to include several other distances.) This may be done using the equation:

$$C = \frac{Q}{\pi\, u\, \sigma_y\, \sigma_z} = \frac{3.18 \times 10^{-1}\, Q}{u\, \sigma_y\, \sigma_z} \qquad 4.10\text{-}6$$

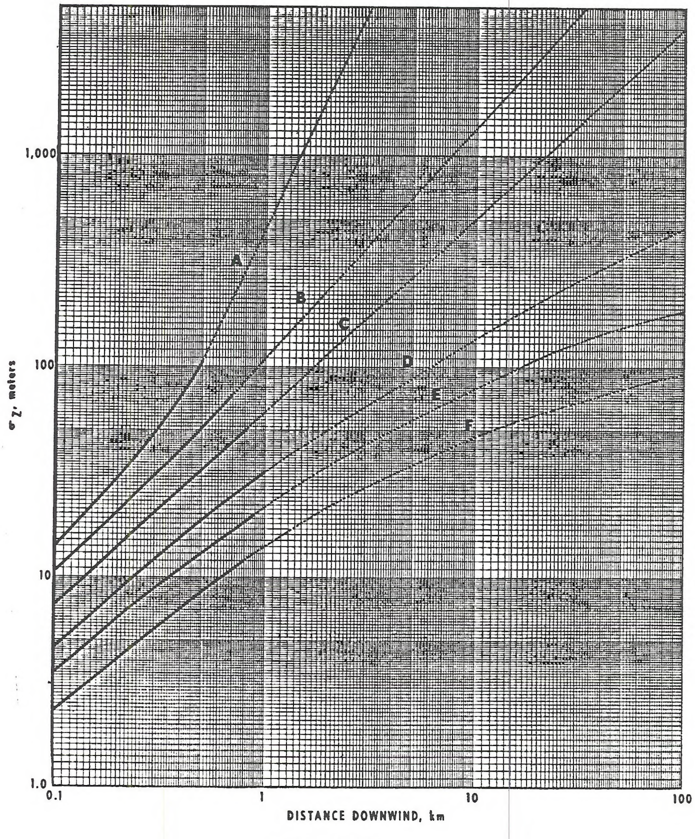


Figure 4.10-3

Vertical Dispersion Coefficient as a Function of Downwind Distance from the Source

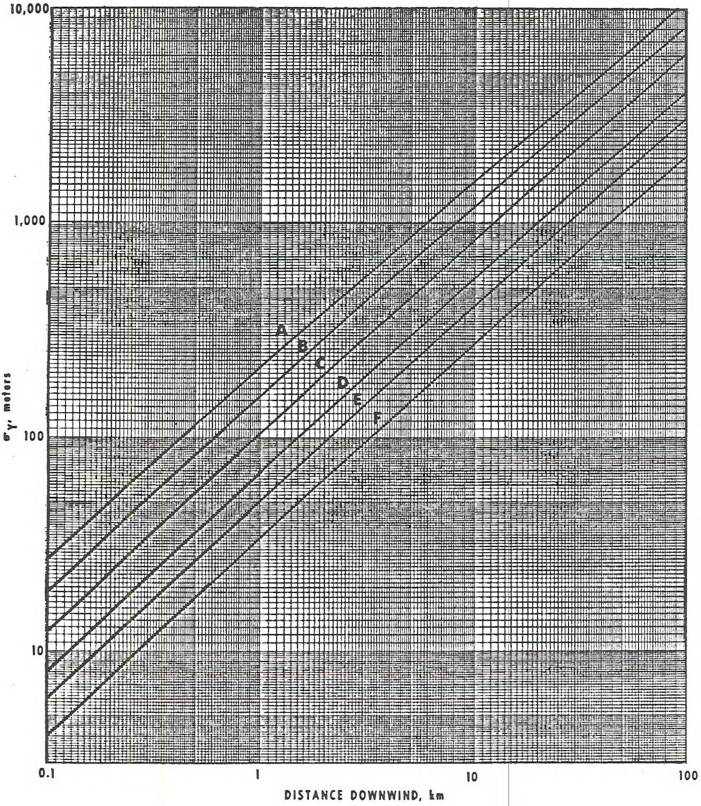


Figure 4.10-4

Horizontal Dispersion Coefficient as a Function of Downwind Distance from the Source

The zero subscript of C, concentration, indicates emission from a ground-level source. If there is a limit to convection (h), concentrations should also be calculated for distances x_1 and x_2 using $\sigma_z = 0.47h_1$ and $\sigma_z = 0.8\ h_1$ respectively. Line segments connecting the calculated concentrations for the various distances will give a plot of concentration with distance.

Calculation of Ground-Level Centerline Concentration From an Elevated Source

Concentrations from an elevated source may be calculated from:

$$C = \frac{Q}{\pi u \sigma_y \sigma_z} \exp - \frac{H^2}{2 \sigma_z{}^2} \qquad 4.10\text{-}7$$

where H is the effective height i.e., the physical stack height plus plume rise, of the elevated source.

Values of $\exp - H^2/2\sigma_z{}^2$ are found in Table 4.10-2. A is the ratio of H/σ_z and B, the expression in the body of the table, is the computed value of the exponential. The E represents x 10 to the power indicated by the following two digits. For example, if A = 3.55, the value of the exponential is 0.183×10^{-2}.

It is possible under light wind situations at nights that the plume from an elevated source will remain aloft with no significant vertical diffusion, in which case the ground-level concentrations would be zero. Vertical spread can then be started at a downwind position corresponding to the wind speed and the estimated time for breakdown of the stable situation.

Graphs for Estimation of Diffusion

Hilsmeier and Gifford (1962) have presented graphs of relative concentration times wind speed (Cu/Q) below the plume centerline, versus downwind distance for various stability classes. Figure 4.10-5 give Cu/Q as a function of x for a ground-level source whereas Figures 4.10-6 through 4.10-8 are for the indicated elevated sources.

Calculation of Off Axis Concentrations

Off-Axis concentrations may be calculated from equation 4.10-1, or by correcting ground-level centerline concentrations by the factor: $\exp - (y^2/2\sigma_y{}^2)$. This may be obtained from Table 4.10-3 for values of y/σ_y.

Plotting Ground-Level Concentration Isopleths

Table 4.10-2

Values of $\text{Exp} - \dfrac{H^2}{2\sigma_z^2}$

$B = \exp - \frac{1}{2}(A)^2$

A	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.00	0.100E 01	0.100E 01	0.100E 01	0.100E 01	0.999E 00	0.999E 00	0.998E 00	0.998E 00	0.997E 00	0.996E 00
0.10	0.995E 00	0.994E 00	0.993E 00	0.992E 00	0.990E 00	0.989E 00	0.987E 00	0.986E 00	0.984E 00	0.982E 00
0.20	0.980E 00	0.978E 00	0.976E 00	0.974E 00	0.972E 00	0.969E 00	0.967E 00	0.964E 00	0.962E 00	0.959E 00
0.30	0.956E 00	0.953E 00	0.950E 00	0.947E 00	0.944E 00	0.941E 00	0.937E 00	0.934E 00	0.930E 00	0.927E 00
0.40	0.923E 00	0.919E 00	0.916E 00	0.912E 00	0.908E 00	0.904E 00	0.900E 00	0.895E 00	0.891E 00	0.887E 00
0.50	0.882E 00	0.878E 00	0.874E 00	0.869E 00	0.864E 00	0.860E 00	0.855E 00	0.850E 00	0.845E 00	0.840E 00
0.60	0.835E 00	0.830E 00	0.825E 00	0.820E 00	0.815E 00	0.810E 00	0.804E 00	0.799E 00	0.794E 00	0.788E 00
0.70	0.783E 00	0.777E 00	0.772E 00	0.766E 00	0.760E 00	0.755E 00	0.749E 00	0.743E 00	0.738E 00	0.732E 00
0.80	0.726E 00	0.720E 00	0.714E 00	0.709E 00	0.703E 00	0.697E 00	0.691E 00	0.685E 00	0.679E 00	0.673E 00
0.90	0.667E 00	0.661E 00	0.655E 00	0.649E 00	0.643E 00	0.637E 00	0.631E 00	0.625E 00	0.619E 00	0.613E 00
1.00	0.607E 00	0.600E 00	0.594E 00	0.588E 00	0.582E 00	0.576E 00	0.570E 00	0.564E 00	0.558E 00	0.552E 00
1.10	0.546E 00	0.540E 00	0.534E 00	0.528E 00	0.522E 00	0.516E 00	0.510E 00	0.504E 00	0.498E 00	0.493E 00
1.20	0.487E 00	0.481E 00	0.475E 00	0.469E 00	0.464E 00	0.458E 00	0.452E 00	0.446E 00	0.441E 00	0.435E 00
1.30	0.430E 00	0.424E 00	0.418E 00	0.413E 00	0.407E 00	0.402E 00	0.397E 00	0.391E 00	0.386E 00	0.381E 00
1.40	0.375E 00	0.370E 00	0.365E 00	0.360E 00	0.355E 00	0.350E 00	0.344E 00	0.339E 00	0.334E 00	0.330E 00
1.50	0.325E 00	0.320E 00	0.315E 00	0.310E 00	0.306E 00	0.301E 00	0.296E 00	0.292E 00	0.287E 00	0.283E 00
1.60	0.278E 00	0.274E 00	0.269E 00	0.265E 00	0.261E 00	0.256E 00	0.252E 00	0.248E 00	0.244E 00	0.240E 00
1.70	0.236E 00	0.232E 00	0.228E 00	0.224E 00	0.220E 00	0.216E 00	0.213E 00	0.209E 00	0.205E 00	0.201E 00
1.80	0.198E 00	0.194E 00	0.191E 00	0.187E 00	0.184E 00	0.181E 00	0.177E 00	0.174E 00	0.171E 00	0.168E 00
1.90	0.164E 00	0.161E 00	0.158E 00	0.155E 00	0.152E 00	0.149E 00	0.146E 00	0.144E 00	0.141E 00	0.138E 00
2.00	0.135E 00	0.133E 00	0.130E 00	0.127E 00	0.125E 00	0.122E 00	0.120E 00	0.117E 00	0.115E 00	0.113E 00
2.10	0.110E 00	0.108E 00	0.106E 00	0.103E 00	0.101E 00	0.991E-01	0.970E-01	0.949E-01	0.929E-01	0.909E-01
2.20	0.889E-01	0.870E-01	0.851E-01	0.832E-01	0.814E-01	0.796E-01	0.778E-01	0.760E-01	0.743E-01	0.727E-01
2.30	0.710E-01	0.694E-01	0.678E-01	0.662E-01	0.647E-01	0.632E-01	0.617E-01	0.603E-01	0.589E-01	0.575E-01
2.40	0.561E-01	0.548E-01	0.535E-01	0.522E-01	0.510E-01	0.497E-01	0.485E-01	0.473E-01	0.462E-01	0.450E-01
2.50	0.439E-01	0.428E-01	0.418E-01	0.407E-01	0.397E-01	0.387E-01	0.377E-01	0.368E-01	0.359E-01	0.349E-01
2.60	0.340E-01	0.332E-01	0.323E-01	0.315E-01	0.307E-01	0.299E-01	0.291E-01	0.283E-01	0.276E-01	0.268E-01
2.70	0.261E-01	0.254E-01	0.247E-01	0.241E-01	0.234E-01	0.228E-01	0.222E-01	0.216E-01	0.210E-01	0.204E-01
2.80	0.198E-01	0.193E-01	0.188E-01	0.182E-01	0.177E-01	0.172E-01	0.167E-01	0.163E-01	0.158E-01	0.154E-01
2.90	0.149E-01	0.145E-01	0.141E-01	0.137E-01	0.133E-01	0.129E-01	0.125E-01	0.121E-01	0.118E-01	0.114E-01
3.00	0.111E-01	0.108E-01	0.105E-01	0.101E-01	0.984E-02	0.955E-02	0.926E-02	0.898E-02	0.871E-02	0.845E-02
3.10	0.819E-02	0.794E-02	0.769E-02	0.746E-02	0.723E-02	0.700E-02	0.679E-02	0.658E-02	0.637E-02	0.617E-02
3.20	0.598E-02	0.579E-02	0.560E-02	0.543E-02	0.525E-02	0.509E-02	0.492E-02	0.477E-02	0.461E-02	0.446E-02
3.30	0.432E-02	0.418E-02	0.404E-02	0.391E-02	0.378E-02	0.366E-02	0.354E-02	0.342E-02	0.331E-02	0.320E-02
3.40	0.309E-02	0.299E-02	0.289E-02	0.279E-02	0.269E-02	0.260E-02	0.251E-02	0.243E-02	0.235E-02	0.227E-02
3.50	0.219E-02	0.211E-02	0.204E-02	0.197E-02	0.190E-02	0.183E-02	0.177E-02	0.171E-02	0.165E-02	0.159E-02
3.60	0.153E-02	0.148E-02	0.143E-02	0.138E-02	0.133E-02	0.128E-02	0.123E-02	0.119E-02	0.115E-02	0.110E-02
3.70	0.106E-02	0.103E-02	0.989E-03	0.952E-03	0.918E-03	0.884E-03	0.851E-03	0.820E-03	0.789E-03	0.760E-03
3.80	0.732E-03	0.704E-03	0.678E-03	0.653E-03	0.628E-03	0.604E-03	0.582E-03	0.560E-03	0.538E-03	0.518E-03
3.90	0.498E-03	0.479E-03	0.460E-03	0.443E-03	0.426E-03	0.409E-03	0.393E-03	0.378E-03	0.363E-03	0.349E-03
4.00	0.335E-03	0.322E-03	0.310E-03	0.297E-03	0.286E-03	0.274E-03	0.263E-03	0.253E-03	0.243E-03	0.233E-03
4.10	0.224E-03	0.215E-03	0.206E-03	0.198E-03	0.190E-03	0.182E-03	0.175E-03	0.168E-03	0.161E-03	0.154E-03
4.20	0.148E-03	0.142E-03	0.136E-03	0.130E-03	0.125E-03	0.120E-03	0.115E-03	0.110E-03	0.105E-03	0.101E-03
4.30	0.966E-04	0.925E-04	0.886E-04	0.849E-04	0.813E-04	0.778E-04	0.745E-04	0.713E-04	0.683E-04	0.653E-04
4.40	0.625E-04	0.598E-04	0.572E-04	0.548E-04	0.524E-04	0.501E-04	0.479E-04	0.458E-04	0.438E-04	0.419E-04
4.50	0.401E-04	0.383E-04	0.366E-04	0.350E-04	0.334E-04	0.320E-04	0.305E-04	0.292E-04	0.279E-04	0.266E-04
4.60	0.254E-04	0.243E-04	0.232E-04	0.221E-04	0.211E-04	0.202E-04	0.193E-04	0.184E-04	0.175E-04	0.167E-04
4.70	0.160E-04	0.152E-04	0.145E-04	0.139E-04	0.132E-04	0.126E-04	0.120E-04	0.115E-04	0.109E-04	0.104E-04
4.80	0.993E-05	0.946E-05	0.902E-05	0.859E-05	0.819E-05	0.780E-05	0.743E-05	0.708E-05	0.674E-05	0.642E-05
4.90	0.611E-05	0.582E-05	0.554E-05	0.528E-05	0.502E-05	0.478E-05	0.455E-05	0.433E-05	0.412E-05	0.392E-05

Table 4.10-2 (Continued)

$B = \exp - \frac{1}{2}(A)^2$

A	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
5.00	0.373E-05	0.354E-05	0.337E-05	0.321E-05	0.305E-05	0.290E-05	0.276E-05	0.262E-05	0.249E-05	0.237E-05
5.10	0.225E-05	0.214E-05	0.203E-05	0.193E-05	0.183E-05	0.174E-05	0.165E-05	0.157E-05	0.149E-05	0.142E-05
5.20	0.134E-05	0.128E-05	0.121E-05	0.115E-05	0.109E-05	0.103E-05	0.982E-06	0.932E-06	0.884E-06	0.838E-06
5.30	0.795E-06	0.754E-06	0.715E-06	0.678E-06	0.643E-06	0.609E-06	0.577E-06	0.547E-06	0.519E-06	0.491E-06
5.40	0.466E-06	0.441E-06	0.418E-06	0.396E-06	0.375E-06	0.355E-06	0.336E-06	0.318E-06	0.301E-06	0.285E-06
5.50	0.270E-06	0.255E-06	0.242E-06	0.229E-06	0.216E-06	0.205E-06	0.194E-06	0.183E-06	0.173E-06	0.164E-06
5.60	0.155E-06	0.147E-06	0.139E-06	0.131E-06	0.124E-06	0.117E-06	0.111E-06	0.104E-06	0.987E-07	0.932E-07
5.70	0.881E-07	0.832E-07	0.786E-07	0.742E-07	0.701E-07	0.662E-07	0.625E-07	0.590E-07	0.556E-07	0.525E-07
5.80	0.496E-07	0.468E-07	0.441E-07	0.416E-07	0.393E-07	0.370E-07	0.349E-07	0.329E-07	0.311E-07	0.293E-07
5.90	0.276E-07	0.260E-07	0.245E-07	0.231E-07	0.218E-07	0.205E-07	0.193E-07	0.182E-07	0.172E-07	0.162E-07
6.00	0.152E-07	0.143E-07	0.135E-07	0.127E-07	0.120E-07	0.113E-07	0.106E-07	0.998E-08	0.939E-08	0.884E-08
6.10	0.832E-08	0.782E-08	0.736E-08	0.692E-08	0.651E-08	0.612E-08	0.576E-08	0.541E-08	0.509E-08	0.478E-08
6.20	0.450E-08	0.423E-08	0.397E-08	0.373E-08	0.351E-08	0.329E-08	0.309E-08	0.291E-08	0.273E-08	0.256E-08
6.30	0.241E-08	0.226E-08	0.212E-08	0.199E-08	0.187E-08	0.175E-08	0.165E-08	0.154E-08	0.145E-08	0.136E-08
6.40	0.128E-08	0.120E-08	0.112E-08	0.105E-08	0.987E-09	0.925E-09	0.867E-09	0.813E-09	0.762E-09	0.714E-09
6.50	0.669E-09	0.627E-09	0.587E-09	0.550E-09	0.516E-09	0.483E-09	0.452E-09	0.424E-09	0.397E-09	0.371E-09
6.60	0.348E-09	0.325E-09	0.305E-09	0.285E-09	0.267E-09	0.250E-09	0.234E-09	0.218E-09	0.204E-09	0.191E-09
6.70	0.179E-09	0.167E-09	0.156E-09	0.146E-09	0.137E-09	0.128E-09	0.119E-09	0.112E-09	0.104E-09	0.974E-10
6.80	0.910E-10	0.850E-10	0.794E-10	0.742E-10	0.693E-10	0.647E-10	0.604E-10	0.564E-10	0.527E-10	0.492E-10
6.90	0.459E-10	0.428E-10	0.400E-10	0.373E-10	0.348E-10	0.325E-10	0.303E-10	0.282E-10	0.263E-10	0.246E-10
7.00	0.229E-10	0.213E-10	0.199E-10	0.186E-10	0.173E-10	0.161E-10	0.150E-10	0.140E-10	0.130E-10	0.121E-10
7.10	0.113E-10	0.105E-10	0.981E-11	0.914E-11	0.851E-11	0.792E-11	0.738E-11	0.687E-11	0.639E-11	0.595E-11
7.20	0.553E-11	0.515E-11	0.479E-11	0.446E-11	0.415E-11	0.386E-11	0.359E-11	0.334E-11	0.310E-11	0.288E-11
7.30	0.268E-11	0.249E-11	0.232E-11	0.215E-11	0.200E-11	0.186E-11	0.173E-11	0.160E-11	0.149E-11	0.138E-11
7.40	0.129E-11	0.119E-11	0.111E-11	0.103E-11	0.955E-12	0.887E-12	0.823E-12	0.764E-12	0.709E-12	0.658E-12
7.50	0.610E-12	0.566E-12	0.525E-12	0.487E-12	0.452E-12	0.419E-12	0.388E-12	0.360E-12	0.334E-12	0.309E-12
7.60	0.287E-12	0.266E-12	0.246E-12	0.228E-12	0.211E-12	0.196E-12	0.181E-12	0.168E-12	0.156E-12	0.144E-12
7.70	0.133E-12	0.124E-12	0.114E-12	0.106E-12	0.980E-13	0.907E-13	0.839E-13	0.777E-13	0.718E-13	0.665E-13
7.80	0.615E-13	0.569E-13	0.526E-13	0.486E-13	0.450E-13	0.416E-13	0.384E-13	0.355E-13	0.328E-13	0.303E-13
7.90	0.280E-13	0.259E-13	0.239E-13	0.221E-13	0.204E-13	0.189E-13	0.174E-13	0.161E-13	0.149E-13	0.137E-13
8.00	0.127E-13	0.117E-13	0.108E-13	0.996E-14	0.919E-14	0.848E-14	0.782E-14	0.722E-14	0.666E-14	0.614E-14
8.10	0.566E-14	0.522E-14	0.481E-14	0.444E-14	0.409E-14	0.377E-14	0.348E-14	0.320E-14	0.295E-14	0.272E-14
8.20	0.251E-14	0.231E-14	0.213E-14	0.196E-14	0.180E-14	0.166E-14	0.153E-14	0.141E-14	0.130E-14	0.119E-14
8.30	0.110E-14	0.101E-14	0.930E-15	0.856E-15	0.787E-15	0.724E-15	0.666E-15	0.613E-15	0.564E-15	0.518E-15
8.40	0.477E-15	0.438E-15	0.403E-15	0.370E-15	0.340E-15	0.313E-15	0.287E-15	0.264E-15	0.243E-15	0.223E-15
8.50	0.205E-15	0.188E-15	0.173E-15	0.159E-15	0.146E-15	0.134E-15	0.123E-15	0.113E-15	0.103E-15	0.949E-16
8.60	0.871E-16	0.799E-16	0.733E-16	0.672E-16	0.617E-16	0.566E-16	0.519E-16	0.476E-16	0.436E-16	0.400E-16
8.70	0.367E-16	0.336E-16	0.308E-16	0.282E-16	0.259E-16	0.237E-16	0.217E-16	0.199E-16	0.182E-16	0.167E-16
8.80	0.153E-16	0.140E-16	0.128E-16	0.117E-16	0.107E-16	0.983E-17	0.900E-17	0.823E-17	0.753E-17	0.689E-17
8.90	0.631E-17	0.577E-17	0.528E-17	0.483E-17	0.441E-17	0.404E-17	0.369E-17	0.337E-17	0.308E-17	0.282E-17
9.00	0.258E-17	0.235E-17	0.215E-17	0.197E-17	0.180E-17	0.164E-17	0.150E-17	0.137E-17	0.125E-17	0.116E-17
9.10	0.104E-17	0.952E-18	0.869E-18	0.793E-18	0.724E-18	0.661E-18	0.603E-18	0.550E-18	0.502E-18	0.458E-18
9.20	0.418E-18	0.381E-18	0.347E-18	0.317E-18	0.289E-18	0.263E-18	0.240E-18	0.219E-18	0.199E-18	0.182E-18
9.30	0.166E-18	0.151E-18	0.137E-18	0.125E-1	0.114E-18	0.104E-18	0.946E-19	0.861E-19	0.784E-19	0.714E-19
9.40	0.650E-19	0.592E-19	0.538E-19	0.490E-1	0.446E-19	0.406E-19	0.369E-19	0.336E-19	0.305E-19	0.278E-19
9.50	0.253E-19	0.230E-19	0.209E-19	0.180E-19	0.173E-19	0.157E-19	0.143E-19	0.130E-19	0.118E-19	0.107E-19
9.60	0.972E-20	0.883E-20	0.802E-20	0.729E-20	0.662E-20	0.601E-20	0.545E-20	0.495E-20	0.450E-20	0.408E-20
9.70	0.370E-20	0.336E-20	0.305E-20	0.277E-20	0.251E-20	0.228E-20	0.207E-20	0.187E-20	0.170E-20	0.154E-20
9.80	0.140E-20	0.127E-20	0.115E-20	0.104E-20	0.943E-21	0.855E-21	0.775E-21	0.702E-21	0.636E-21	0.576E-21
9.90	0.522E-21	0.472E-21	0.428E-21	0.387E-21	0.351E-21	0.318E-21	0.288E-21	0.260E-21	0.236E-21	0.213E-21

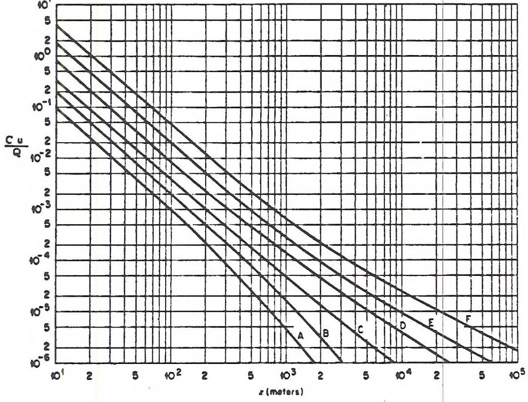


Figure 4.10-5

Values of $\frac{Cu}{Q}$ for a Ground Level Source

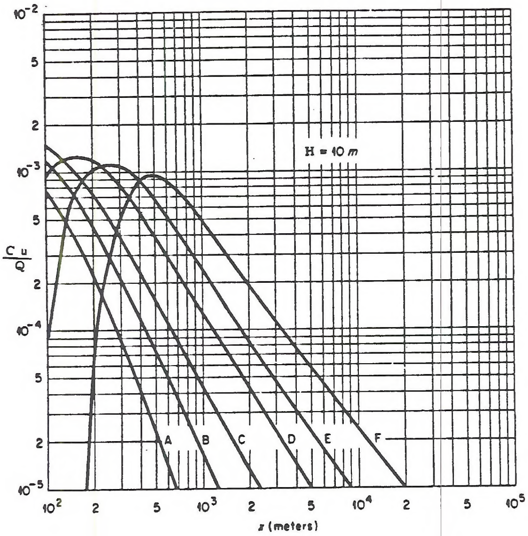


Figure 4.10-6

Values of $\frac{Cu}{Q}$ for H = 10 meters

1 meter = 39.37 inches

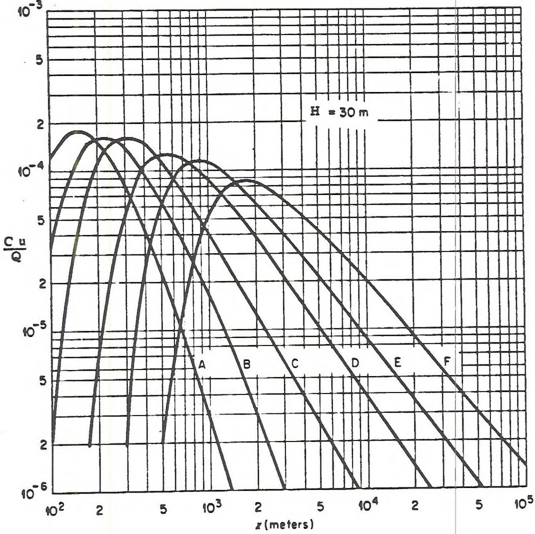


Figure 4.10-7

Values of $\frac{Cu}{Q}$ for H = 30 meters

1 meter = 39.37 inches

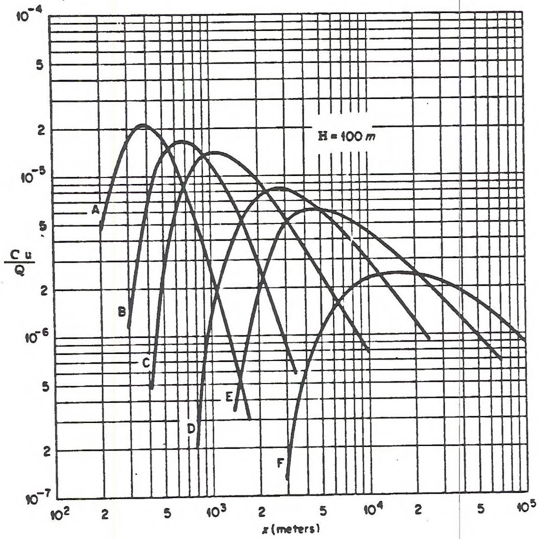


Figure 4.10-8

Values of $\frac{Cu}{Q}$ for H = 100 meters

1 meter = 39.37 inches

Table 4.10-3

Values of Exp $(y^2/2\sigma_y^2)$ for y/σ_y

y/σ_y	$\exp(y^2/2\sigma_y^2)$
0	1.00
0.1	1.01
0.2	1.02
0.3	1.05
0.4	1.08
0.5	1.13
0.6	1.20
0.7	1.28
0.8	1.38
0.9	1.50
1.0	1.65
1.2	2.05
1.4	2.66
1.5	3.08
1.6	3.60
1.8	5.05
2.0	7.39
2.15	10
3.04	10^2
3.72	10^3
4.29	10^4
4.80	10^5

It may be of interest in a given application to plot the position of the centerline of the plume and to determine areas covered by concentrations greater than a given magnitude. First the axial position of the plume must be known. The mean wind direction will determine the position. The surface wind may be used up to 1 km. Between 1 km and 100 km, the average of the surface direction and the geostrophic direction backed (counter-clockwise change in direction) by 10^{o} will give a close approximation. The wind direction should be a mean through the vertical extent of the plume (about $2\ \sigma_z$).

In order to draw lines of equal concentration, it is easiest to locate the centerline concentration, that is $\exp(y^2/2\ \sigma_y^2)$ times the concentration desired, on a log/log plot of centerline concentrations against distance. The value of y (the off-axis distance), can then be found by knowing the y/σ_y value corresponding to the appropriate $\exp(y^2/2\ \sigma_y^2)$ (See Table 4.10-3) and the value of   for this particular distance (from Figure 4.10-4). The position corresponding to the downwind distance and the off-axis distance can then be plotted. After a number of these points have been plotted, the concentration isopleth may be drawn and the area determined by using a planimeter. This assumes that the plume has a Gaussian distribution across wind. If there is a systematic veering or backing of the wind direction over a range that is large compared to the width of the trace, the plume may be assumed to be uniform in distribution across the width ($4.3\ \sigma$) of the plume and the concentration will be 0.58 of the calculated centerline concentration.

Areas Within Concentration Isopleths

Figure 4.10-9 gives areas within ground-level concentration isopleths in terms of Cu/Q for a ground-level source for various stability categories (Hilsmeier and Gifford, 1962).

Rapid Determination of Maximum Concentration

The maximum concentration of pollutants will occur along the centerline of the plume where y is zero, as indicated in equation 4.10-7 above. The distance downwind, at which the maximum concentration occurs at ground level, is a function of effective source height and stability. Figure 4.10-10 is a nomogram from which the relative value of the maximum concentration can be determined given the stability and effective source height. If the relative value of that concentration is multiplied by $Q/\bar{u}$, the maximum concentration for a specific set of conditions is obtained. The nomogram is designed for source strength expressed in grams/sec and wind speed in meters/sec.

Accuracy of Computations

The method will, in general, give only approximate estimates of concentrations, especially if wind fluctuation measurements are not available and estimates of dispersion are

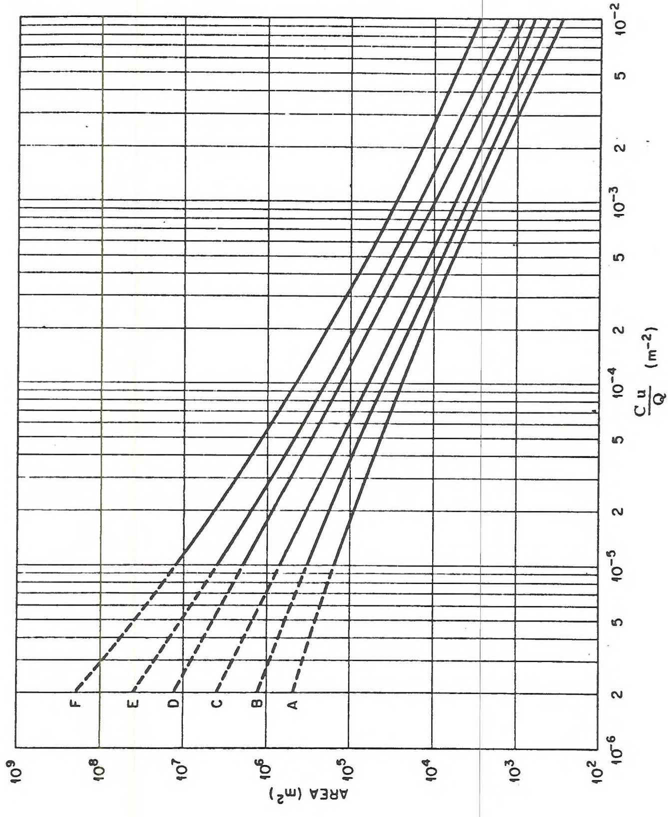


Figure 4.10-9

Area Within Ground Level Concentration Isopleths for

Values of Cu/Q and Atmospheric Stability

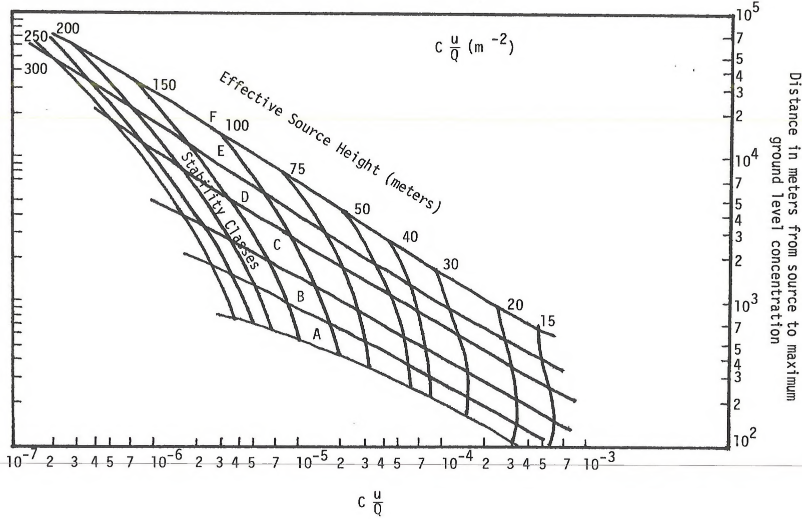


Figure 4.10-10

Distance from Source and Relative Value of Maximum Concentations for Various Source Heights and Stability Classes

1 meter = 39.37 inches

obtained from Figures 4.10-3 and 4.10-4. In the unstable and stable cases, errors of σ_z of several fold may occur for longer travel distances. There are cases where σ_z may be expected to be within a factor of 2. These are: 1) all stabilities for distances of travel of a few hundred meters in open country; 2) neutral to moderately unstable conditions for distances of a few kilometers; and 3) unstable conditions in the first 1000 meters above ground with a marked inversion thereafter for distances of 10 km or more. Uncertainties in the estimates of σ_y are in general less than those of σ_z except when the wind field is indefinite. In this case, the estimate of concentrations from the plume would be the same except that a wind range should be allowed for the direction of the plume, up to 360^o. For extremes of stable and unstable conditions at distances between 50 and 100 km calculated concentrations may differ from true concentrations by an order of magnitude. For these distances, under neutral conditions, calculated concentrations should be within a factor of 5 of true concentrations.

EXERCISES WITH DIFFUSION PARAMETERS

1. What stability category would be most likely to occur when the wind is 6 - 8 m/sec? (D)

2. If the sky is overcast - synonymous with cloudy - what would the stability category most likely be? (D)

3. What would the stability category most likely be on a sunny April afternoon when the wind is 3 m/sec? (A or B)

4. If the surface wind at night is 3 m/second there is 5/8 coverage of low clouds, what is the most likely stability category? (D or E)

5. What are σ_y and σ_z at 150 m from a source under B stability? (σy = 27.5m, σz = 15.5m)

6. How much difference is there in σ_z at 5 km under D and F stability? (55m)

7. What is the value of σ_y at 30 km under C stability? (2200m)

8. At 300 m how many times larger is σ_y under B stability than under D stability? (2.4)

9. Under E stability how much greater is the horizontal dispersion factor than the vertical dispersion factor at 300m? (7.7)

10. If the value of H/σ_z is 1.8, what is the value of exp - - 1/2 $(H/\sigma_z)^2$? (1.6)

11. The value of exp - $1/2(H/\sigma_z)^2$ is 2.2×10^{-3}. What is H/σ_z? (3.49)

12. Under D stability and a wind speed of 5 m/sec, a plume is emitted at 100 m above the ground. What is the value of C/Q at 4 km?
(1.4×10^{-6} sec/m^3)

13. What is the area enclosed by an isopleth whose Cu/Q value is 4×10^{-4} m^{-2}, when the stability category is B? ($10^4 m^2$)

EXAMPLE DIFFUSION COMPUTATIONS

#1 A power plant burns 10 tons per hour of 3% sulfur coal, releasing the effluent from a single stack. On a sunny summer afternoon, the wind speed at 10 meters is 4 m/sec from the northeast. The morning radiosonde run in the vicinity has indicated that a frontal inversion aloft will limit the convection to 1500 meters. The 1200 meter wind is from 30° at 5 m/sec. The effective height of emission is 150 meters. What is the maximum concentration and where does it occur?

Solution: On a sunny, summer afternoon the insolation should be strong. From Table 4.10-1, strong isolation and 4 m/sec wind yields class B stability. The amount of sulfur burned is:

$$\text{Sulfur} = \frac{10 \text{ tons}}{\text{hour}} \times \frac{2000 \text{ lbs}}{\text{ton}} \times 0.03 \text{ sulfur} = 600 \text{ lbs/hr.}$$

Sulfur has a molecular weight of 32 and combines with O_2 with a molecular weight of 32; therefore, for every pound of sulfur burned, there results two pounds of SO_2.

$$Q = \frac{2\ SO_2}{S} \times \frac{600 \text{ lbs. S}}{\text{hr.}} \times \frac{453.6 \text{ gms/lb.}}{3600 \text{ sec/hr}} = 151 \text{ gms. } SO^2\text{/sec.}$$

The maximum concentration may be found by using Figure 4.10-10. Given stability class B and effective source height of 150 m., one may enter the nomogram and read the Cu/Q value of 8×10^{-6} from the abscissa. Solving for the maximum concentration, C (max), using the wind speed, u, of 4 m/sec and the source strength, Q, of 151 gms. SO_2/sec yields.

$$C_{(max)} = 8 \times 10^{-6} \times \frac{151 \text{ gms/sec}}{4 \text{ m/sec}} = 3 \times 10^{-4} \text{ gm/m}^3$$

The distance from the power plant at which the maximum concentration occurs under these meteorological conditions can be read from the ordinate in Figure 4.10-10. This distance is 1000m.

#2 Using the conditions in the above problem, draw a graph of centerline sulfur dioxide concentrations beneath the plume with distance from 100 meters to 100 km.

Solution: Since the frontal inversion limits the convection to h_1 = 1500 meters, the distance where σ_z = 0.47 h_1 = 700 meters is x_1 = 5.5 km. At distances equal to or greater than 2 x_1 = 11.0 km, σ_z = 0.8 h_1 = 1200 meters. Equation 4.10-7 is used to find concentration as a function of distance.

$$C = \frac{151}{\pi\, u\, \sigma_y\, \sigma_z} \exp - \frac{1}{2} \left(\frac{H}{\sigma_z}\right)^2$$

In this case H = 150 meters. Solutions for this equation are given in Table 4.10-4. The values of concentrations in Table 4.10-4 are plotted against distance in Figure 4.10-11.

#3 Draw a graph of concentration versus cross-wind distance at a downwind distance of 800 meters for the conditions of problems 1 and 2.

Solution: From problem 2, the centerline concentration at 800 meters is 2.9×10^{-4} gms/m^3. To determine the concentrations at distances y from the x axis, the centerline concentration must be multiplied by the factor $\exp -1/2(y/\sigma_y)^2$. σ_y = 120 meters at x = 800 meters. Values for this computation are given in Table 4.10-5.

The preceeding exercises illustrate one of the simplest approaches to air quality modeling. Numerous levels of sophistication can be incorporated into the basic Gaussian modeling approach to determine pollution concentrations at downwind receptor locations. As mentioned before, the next level incorporates mathematical simulations of plume rise. Plume rise is mainly a function of momentum and thermal buoyancy. Terms related to one or both of these factors are included in nearly all plume rise formulas. For cold stacks (JETS), those with emissions of less than 10 to 20°F above ambient, momentum is probably the most important factor. On the other hand, for hot stacks, when gases are warmer than 200°F, buoyancy is the most important aspect of the plume rise formula. Numerous plume rise formulas have been proposed by a multitude of qualified investigators. No one formula provides the best estimate for all types of stacks and atmospheric conditions. The most widely accepted plume rise formulas were derived by Holland (1953) and Briggs (1969). The basics of their plume rise simulation formulae are applied by most Environmental Protection Agency (EPA) accepted air quality models.

Table 4.10-4
Solutions for Problem #2

Col. a	Col. b	Col. c	Col. d	Col. e	Col. f	Col. g
x (km)	u (m/sec)	σ_y m	σ_z m	H/σ_z	$\exp - \frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2$	C gms/m^3
0.3	4	52	30	5.0	3×10^{-6}	2.3×10^{-8}
0.5	4	77	53	2.83	1.7×10^{-2}	5.0×10^{-5}
0.8	4	120	93	1.61	0.27	2.9×10^{-4}
1	4	150	125	1.20	0.48	3.1×10^{-4}
2.8	4.5	375	700	0.21	0.98	4.0×10^{-5}
5.6	4.5	700	1200	0.125	0.98	1.25×10^{-5}
10	4.5	1200	1200	0.125	0.98	7.3×10^{-6}
100	4.5	8400	1200	0.125	0.98	1.04×10^{-6}

Col. c from Figure 4.10-4
Col. d from Figure 4.10-3
Col. e 150 m over value in Col. d
Col. f Value in Table 4.10-2 corresponding to H/σ_z in Col. e
Col. g Solution to equation 4.10-7

Table 4.10-5

y (m)	y/σ_y	$\exp - \frac{1}{2}(y/\sigma_y)^2$	C(y) gms/m^3
$\pm$ 100	0.834	0.7	2.03×10^{-4}
$\pm$ 200	1.67	0.25	7.25×10^{-5}
$\pm$ 300	2.5	4.2×10^{-2}	1.22×10^{-5}
$\pm$ 400	3.33	3.7×10^{-3}	1.07×10^{-6}

This is graphed in Figure 4.10-12

1 m = 3.281 feet
1 km = 0.6214 miles
1 m/s = 3.281 feet/second
1 gm/m^3 = 6.243×10^{-7} lbs/feet^3

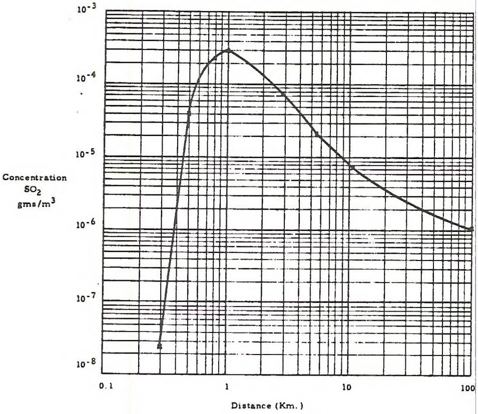


Figure 4.10-11

Concentration of SO_2 (gms/m^3) as a Function of Distance (km).(Problem 2)

1 gm/$_m$3 = 6.243 x 10^{-7} lbs/ft^3

1 km = 0.6214 mi

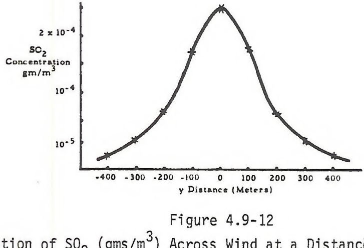


Figure 4.9-12

Concentration of SO_2 (gms/m^3) Across Wind at a Distance of 800 Meters (Problem 3)

1 gm/$_m$3 = 6.243 x 10^{-7} lbs/ft^3

1 m = 1.094 yds

Briggs in his recent publication, <u>Plume Rise</u> (1969), has presented both a critical review of the subject and a series of equations applicable to a wide range of atmospheric and emission conditions. These equations are being employed by an increasing number of meteorologists and are used almost exclusively within EPA. An important result of this study is that the rise of buoyant plumes from fossil-fuel plants with a heat emission of 20 megawatts (MW) - 4.7×10^6 cal/sec - or more can be calculated from the following equations under neutral and unstable conditions.

$$\Delta H = 1.6\ F^{1/3}\ u^{-1}\ x^{2/3} \qquad 4.10\text{-}8$$

$$\Delta H = 1.6\ F^{1/3}\ u^{-1}\ (10\ h_s)^{2/3} \qquad 4.10\text{-}9$$

where:

ΔH = plume rise
F = buoyancy flux
u = average wind at stack level
x = horizontal distance downwind of the stack
h_s = physical stack height

Equation 4.10-8 should be applied out to a distance of 10 h_s from the stack and equation 4.10-9 can be used for greater distances.

The buoyancy flux term, F, may be calculated from:

$$F = \frac{g\ Q_H}{\pi\ c_p\ \rho T} \simeq 3.7 \times 10^{-5}\ \frac{m^4/sec^3}{cal/sec}\ Q_H \qquad 4.10\text{-}10$$

where:

g = gravitational acceleration
Q_H = heat emission from the stack, cal/sec
c = specific heat of air at constant pressure
p = average density of ambient air
T = average temperature of ambient air

Alternatively, if the stack gases have nearly the same specific heat and molecular weight as air, the buoyancy flux may be determined from:

$$F = \frac{\Delta T}{T_s}\ g\ v_s\ r^2 \qquad 4.10\text{-}11$$

Notation has been previously defined.

In stable stratification, equation 4.10-8 holds approximately to a distance $x = 2.4\ us^{-1/2}$. S may be defined as a stability parameter:

$$s = \frac{g}{T} \quad \frac{\partial \theta}{\partial z} \qquad 4.10\text{-}12$$

where:

$\frac{\partial \theta}{\partial z}$ = lapse rate of potential temperature

Beyond this point the plume levels off at about

$$\Delta H = 2.4 \left(\frac{F}{u\ s} \right)^{1/3} \qquad 4.10\text{-}13$$

However, if the wind is so light that the plume rises vertically, the final rise can be calculated from:

$$\Delta H = 5.0\ F^{1/4}\ s^{-3/8} \qquad 4.10\text{-}14$$

For other buoyant sources, emitting less than 20 MW of heat, a conservative estimate will be given by equation 4.10-8 up to a distance of:

$$x = 3x^* \qquad 4.10\text{-}15$$

where:

$$x^* = 0.52 \left[\frac{\text{sec}^{6/5}}{\text{ft.}^{6/5}} \right] F^{2/5}\ h_s^{3/5=} \qquad 4.10\text{-}16$$

which is the distance at which atmospheric turbulence begins to dominate entrainment.

Sophisticated modeling more complex than the simple Gaussian are often required. These sophisticated algorithms applied to the basic Gaussian approach include the computation of downwind ground level concentrations as a function of stability class and wind speed. Such an approach would incorporate wind speeds as a function of stability class. Further sophistication in the Gaussian modeling approach would incorporate relative frequency distributions of wind speeds, wind direction and stability class. This type of model would be useful in isolating long-term air pollution concentrations in the study area.

There is a limitless number of levels of sophistication with regard to the Gaussian model. The accuracy and refinement of each generation of the model depends upon the quality and

resolution of the data base used. As the problem becomes more complex, more sophisticated numerical models must be employed particularly in instances where terrain or conversion effects become important. Such modeling is beyond the scope of this document, however the EPA may be contacted for more information on dispersion models such as the Climatological Dispersion Model (CDM), the Air Quality Display Model (AQDM), the Valley Model, and the Texas Climatological Model (TCM).

4.11 ASSISTANCE IN DISPERSION METEOROLOGICAL PROBLEMS

References

- Abstracts

Meteorological and Geoastrophysical Abstracts
American Meteorological Society
45 Beacon Street
Boston 8, Mass.

- Periodicals

Bulletin of the American Meteorological Society
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Journal of Applied Meteorology
American Meteorological Society

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- Books

American Meteorological Society, On Atmospheric Pollution,
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Geiger, R. (Transplanted by Scripta Technica Inc.) The Climate Near the Ground.
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Cambridge, Mass. 1965.

Professional Meteorological Consultants

Professional meteorologists advertise their services in the Professional Directory section of the Bulletin of the American Meteorological Society. In the May 1979 Bulletin, 83 such firms and individuals were listed. The American Meteorological Society has in the last several years instituted a program of

certifying consulting meteorologists. Of the 83 professional services listings in the Bulletin, 40 list Certified Consulting Meteorologists.

Local U.S. National Weather Service Office

A wealth of meteorological information and experience is available at the local city or airport Weather Service Office pertaining to local climatology, pecularities in local micro-meteorological conditions including topographic effects, and exposure and operating characteristics of meteorological instruments. The Air Stagnation Advisories are received here by teletype from the National Meteorological Center. Often the public telephones the Weather Service with air pollution complaints which the meteorologists may have traced back to a specific source by examining local wind circulations. Through personal contact with the meteorologist-in-charge (MIC), specific, localized forecasts may be arranged to support a short-term air pollution investigation or sampling program.

Contract Work

Many universities do contract work for private organizations and for government agencies on meteorological problems.

4.12 GLOSSARY OF TERMS

Adiabatic	A thermodynamic change of state of a system in which there is no transfer of heat or mass across the boundaries of the system. In an adiabatic process, compression always results in warming, expansion in cooling.
Adiabatic Diagram	A thermodynamic diagram with temperature as abscissa and pressure to the power 0.286 as ordinate, increasing downward.
Advection Inversion	A type of inversion which occurs over an area due to the advection of a stable layer (e.g., marine inversion noted along coastal California are the result of the advection of cool, stable air from the nearby Pacific.
Aerodynamic	Pertaining to forces acting upon any solid or liquid body moving relative to a gas. (especially air).
Air Basin	An area created by topographic boundaries which serves to contain air pollutants emitted into the area by pollution sources and to restrict air exchange with other air basins.
Air Flow Pattern	The typical movement of air currents as graphed on wind roses.
Air Parcel	An imaginary body of air to which may be assigned any or all of the basic dynamic and thermodynamic properties of atmospheric air.
Algorithm	A procedure for solving a problem (as in mathematics) that frequently involves repetition of an operation.
Backing	According to general internationally accepted usage, a change in wind direction in a counterclockwise sense.
Bimodal	A distribution having two maxima.
Black Body	A body which absorbs all incident electromagnetic radiation; i.e., one which neither reflects nor transmits any incident radiation.
Buoyancy Flux	An empirical term used in plume rise calculations to define the heat content of an industrial source.

Burn/No-Burn Forecasts	Used to determine when weather conditions favor the rapid dispersion of pollutants created by the burning of agricultural wastes and other industrial operations.
Calm	A period when the air is motionless. In the United States, the wind is reported as calm if it has a speed of less than one mile per hour (or one knot).
Centerline Concentration	The concentration of gaseous pollutants or aerosols at the center of the plume.
Channeling	The effect of terrain, particularly valleys, in modifying the prevailing winds along the path of lowest terrain heights.
Cold Stacks (Jets)	Cold, non-buoyant sources with emission temperatures less than 10 to 20°F above ambient temperatures.
Condensation Levels	The level at which a parcel of moist air lifted dry adiabatically would become saturated.
Coning	When the vertical temperature gradient is between dry adiabatic and isothermal, slight instability occurs with both horizontal and vertical mixing. An industrial plume tends to become cone shaped, hence the name.
Constant Level Balloons	A balloon designed to float at a constant pressure level.
Convective Thundershowers	Showers caused when layers of air are forced to rise rapidly.
Diffusion	In meteorology, the exchange of fluid parcels between regions in space, in the apparently random motions of a scale too small to be treated by the equations of motion.
Digitized Data	Data which is recorded in a computer acceptable format (as opposed to analog or strip chart data).

Dispersion Modeling	The mathematical representation or simulation of transport precesses that occur in the atmosphere.
Dispersion Potential	The ability of a system such as the atmosphere, to dilute the concentration of a substance or pollutant by molecular and turbulent motion; e.g., smoke in the air.
Diurnal	Daily, especially pertaining to actions which are completed within twenty-four hours and which recur every twenty-four hours.
Downwash	The condition resulting when strong winds push a plume rapidly to the surface, resulting in high ground-level pollution concentrations. The phenomenon is usually observed in the lee of buildings.
Drainage Flow	Typical of mountain regions, and caused by the gravitation of cold air off high ground.
Dry Adiabatic Lapse Rate	The rate of decrease of temeprature with height when dry air is lifted adiabatically (due to expansion as it is lifted to lower pressure).
Effective Stack Height	The physical stack height plus plume rise, i.e., the point above ground at which the gaseous effluent becomes esentially level.
Elevated Inversion	An inversion layer above the immediate surface. Such an inversion inhibits dispersion of bouyant pollutants, such as those given off by power facilities and refineries.
Empirical	An approach based upon observation and experimentation.
Environmental Lapse Rate	The rate of decrease of temperature with elevation at at given time and place.
Exit Characteristics	Parameters pertaining to a gas exiting from a stack including gas temperature, exit velocity, emission rate, stack height, and stack diameter.

Fanning	When the atmosphere is stabily stratified, an industrial plume will spread horizontally but little if any vertically.
Fire Management	The practice of controlling range undergrowth, such as chapparal, through controlled burning.
Fire Weather	The state of the weather with respect to its effect upon the kindling and spreading of forest fires.
Fluid Dynamics	The level of physics that treats the action of force on fluids and gases in motion or at rest.
Freezing Level	The lowest altitude in the atmosphere over a given location at which the air temperature is 32°F.
Frontal Inversion	A temperature inversion encountered in the atmosphere, upon vertical ascent through a sloping front.
Fugitive Dust	Solid air borne particles emitted from any source other than a stack.
Fugitive Source	A source emitting pollutants other than from a stack.
Fumigation	The rapid mixing of a fanning plume down to the ground, such as during inversion breakup.
Gaussian Diffusion Equation	An equation used to evaluate the concentration of gases or aerosols assuming a Gaussian or normal distribution.
Horizontal Dispersion Coefficient	The horizontal standard deviation of plume pollutant concentration. The parameter varies as a function of downwind distance and atmospheric stability.
Induced Flow	A flow of air caused by uneven heating of terrain and its associated air parcels.
Insolation	Solar radiation received at the earth's surface.
Inversion	A departure from the usual decrease or increase with altitude of the value of an atmospheric property (almost always of

	temperature). In a temperature inversion, temperature increases with altitude. A tmeperature inversion is stable, allowing little turbulent exchange to occur.
Inversion Layer	That layer of air which departs from the usual decrease in temperature with increasing altitude.
Isopleth	A line of equal or constant value of a given quantity, with respect to either space or time.
Isothermal	Of equal or constant temperature, with respect to either space or time.
Jet (Low-Level)	A high-speed wind that attains its velocity through channeling due to terrain configuration such as a narrow mountain pass or canyon.
K-Theory	K-theory or gradient transport theory assumes that turbulent diffusion is proportional to the local mean concentration gradient.
Land Breeze	A coastal breeze blowing from land to sea, caused by the temperature difference when the sea surface is warmer than the adjacent land.
Lapse Rate	The decrease of an atmospheric variable (almost always temperature) with height.
Line Source	A source of pollutants occurring at a reasonably continuous rate along a fixed line (e.g., highway).
Lofting	Lofting of an industrial plume occurs when there is a superadiabatice layer above a surface inversion.
Looping	The looping of an industrial plume occurs with a superadiabatic lapse rate.
Mixing Height/ Depth	Height (Depth) of the layer of air where well-mixed conditions exist, usually the height of the first significant inversion above the surface.
Mixing Layer	That thin layer of the troposphere available for the dispersion of pollutants released near the surface.
Momentum Exchange	The turbulent transfer of momentum; the product of mass and velocity.

Mountain Flow	The regular flow of air around portions of raised terrain. Air will stream toward and up mountain slopes during the day and downward and away during the night.
Neutral Atmospheric Stability	Neutral stratification of the atmosphere, i.e., the lapse rate is equal to the dry-adiabatic lapse rate, therefore, a parcel of air displaced vertically will experience no buoyant acceleration.
Nocturnal Air Flow	A flow pattern characteristic of clear nights and rapid radiational cooling, which tends to stabilize the atmospehre promoting air flow from higher terrain towards low lying areas.
Nucleation	The condensation out of molecules on airborne particles.
Numerical Modeling	The development of a means of computing the future state of the atmosphere from the basic theoretical equations which govern that state.
Orographic	Of, pertaining to, or caused by mountains.
Pasquill's Stability Categories	Stability classes as defined by Dr. F. Pasquill of the British Meteorological Service, including extremely unstable, unstable, slightly unstable, neutral, slightly stable, and stable.
Persistence	Time period over which a certain parameter is maintained.
Physical Modeling	Physical modeling is based uopon the actual simulation of events in the real atmosphere or in a scale model.
Physical Stack Height	Actual height of a stack, i.e., a pollutant source.
Plume	A large, conspicuous cloud of smoke, dust, or water vapor arising from a stack.

Plume Rise	The velocity and heat of an industrial source will cause it to rise to its effective stack height. The difference between the physical and effective stack heights is called plume rise.
Positive Net Radiation	Amount of incoming solar radiation in excess of outgoing terrestrial radiation.
Prevailing Wind(s)	The wind direction(s) most frequently observed during a given period.
Profile	A graph of the value of a scalar quantity (such as temperature) versus a horizontal, vertical, or time scale.
Pseudo-Adiabatic Lapse Rate	The rate of decrease of temperature with height of an air parcel lifted at saturation through the atmosphere. Less than the dry adiabatic lapse rate.
Radiational Cooling	Cooling of the earth's surface and surrounding air accomplished (mainly at night) whenever the earth's surface experiences a net loss of heat.
Radiational Inversion	An inversion at the surface due to radiation cooling.
Radiosonde	A balloon-borne instrument used for measuring and transmitting weather data, such as pressure, temperature and humidity.
Re-entrainment	The mxing of environmental air into an organized air current of which it formally was a member.
Regime	The character of the seasonal distribution of a weather phenomenon at any place; e.g., the summer sea breeze regime.
Screening Level	A simplistic approach designed to determine the need for additional, more detailed analyses.
Sky Cover	The amount of sky covered or concealed by clouds or other obscuring phenomena.

Slope Winds	Winds caused by uneven surface heating and cooling in areas of rugged terrain.
Smoke Sensitive Area	An area which, due to high population density, recreational value or scenic beauty, is considered particularly sensitive to smoke plumes from forest management burning.
Solar Altitude	The elevation angle of the sun above the horizon.
Solar Insolation	Solar radiation received at the earth's surface.
Sorption	The deposition of molecules due to collision with an object.
Sounding	Any penetration of the natural environment for scientific observation. In meteorlogy, commonly refers to the environmental lapse rate.
Stability	A measure of the extent to which vertical and horizontal mixing will take place. Commonly measured as unstable, neutral or stable.
Stable	The lapse rate is less than the dry adiabatic lapse rate and vertical motion is suppressed.
STAR (STability ARray)	A description of a type of meteorlogical program developed by the National Climatic Center in Asheville, North Carolina. The program provides joint frequency distributions of wind speed, wind direction, and atmospheric stability class.
Stability Wind Roses	Diagrams designed to show the distribution of wind direction experienced at a given location over a desired time period for a given atmospheric stability class.
Stack	Any chimney, flue, conduit, or duct arrangted to conduct emissions to the outside air.
Statistical Modeling	Statistical modeling is based upon the stochastic nature of turbulence and describes diffusion as an ensemble average of many particles emitted from a source.
Sub-Adiabatic	A lapse rate which is less than the dry adiabatic lapse rate.

Subsidence Inversion	A temperature inversion produced by the warming of a layer of descending air. The effect is the creation of a limited mixing volume below the stable layer.
Super-Adiabatic	A lapse rate which is greater than the dry adiabatic lapse rate.
Surface Based Inversion	An inversion layer of stable air close to the ground. Such an inversion inhibits dispersion of fugitive dust and other non-buoyant sources of pollutants.
Surface Boundary Layer	The thin layer of air immediately adjacent to the earth's surface.
Surface Data	Observations of the weather from a point at the surface of the earth, as opposed to upper-air or winds-aloft observations.
Surface Roughness	Irregulatities of the earth's surface (provided by trees, buildings, etc.) which increases air turbidity, and consequently, pollutant dispersion.
Synoptic Scale Winds	Strong winds created by weather patterns of high and low pressure systems in the lower troposphere.
Temperature Profile	A graph of temperature versus a horizontal, vertical, or time scale.
Temperature Sounding	Upper-air observations of temperature as taken by a radiosonde.
Thermal Buoyancy	The impetus provided by heat for an emission to rise or remain suspended in the atmosphere.
Thermal Low	An area of low atmospheric pressure due to high temperatures caused by intensive heating at the earth's surface.
Transport	The rate by which a substance or quantity, such as heat, suspended particles, etc., is carried past a fixed point.

Trapping	When an inversion occurs aloft such as a frontal or subsidence inversion, a plume released beneath the inversion will be trapped beneath it.
Trajectory Analyses	The depiction of regional wind direction patterns at the surface of the earth, as generated from the most frequent wind direction occurring at each of several stations in an area for selected averaging periods.
Tropopause	The boundary between the troposphere and the stratosphere.
Troposphere	The lowest 10 to 20 km (6-12 miles) of the atmosphere. It is characterized by decreasing temperature with height, appreciable vertical wind motion, appreciable water vapor content, and weather.
Typical Conditions	The most commonly occurring combination of the key dispersion factors - wind speed, wind direction, and atmospheric stability class. Knowledge of the most commonly occurring dispersion condidtions provides some indication of the effect of an existing or proposed pollution source.
Unstable	The environmental lapse rate is greater than the dry adiabatic lapse rate and vertical turbulence is enhanced.
Valley Winds	A wind which ascends a mountain valley during the day.
Veering	According to general international usage, a change in wind direction in a clockwise sense.
Ventilate	To cause to circulate as in the dispersion of air pollutants.
Vertical Circulation	The movement or mixing of air along a vertical axis.
Vertical Dispersion Coefficient	The vertical standard deviation of plume pollutant concentration. The parameter varies as a function of downwind distance and atmospheric stability.

Vertical Temperature Profile	A graph of temperature versus altitude.
Vertical Wind Profile	A graph of the variation of mean wind speed with height in the surface boundary layer.
Virtual Source	The theoretical location of a point source with respect to an actual area source which would result in plume dispersion at the actual point of emission indicative of the area source.
Wind Tunnel	A small scale model of the atmosphere which permits experimentation in the laboratory.
Winds Aloft	Wind speeds and directions at various levels in the atmosphere above the surface.
Worst-case Conditions	That combination of wind speed, wind direction, and atmospheric stability class that would result in the greatest possible pollutant impact of an existing or proposed source.

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